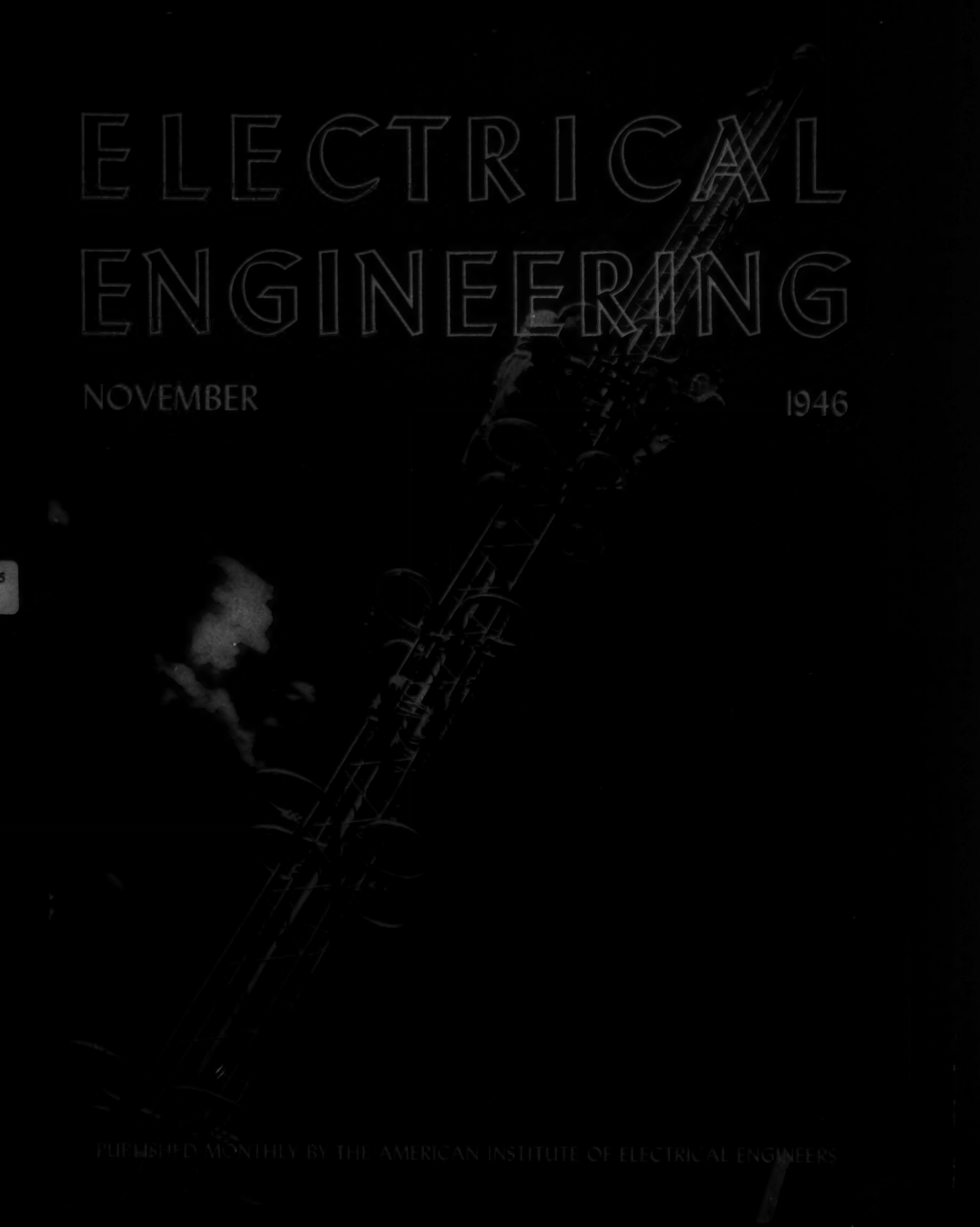
ELECTRICAL ENGINEERING

NOVEMBER 1946



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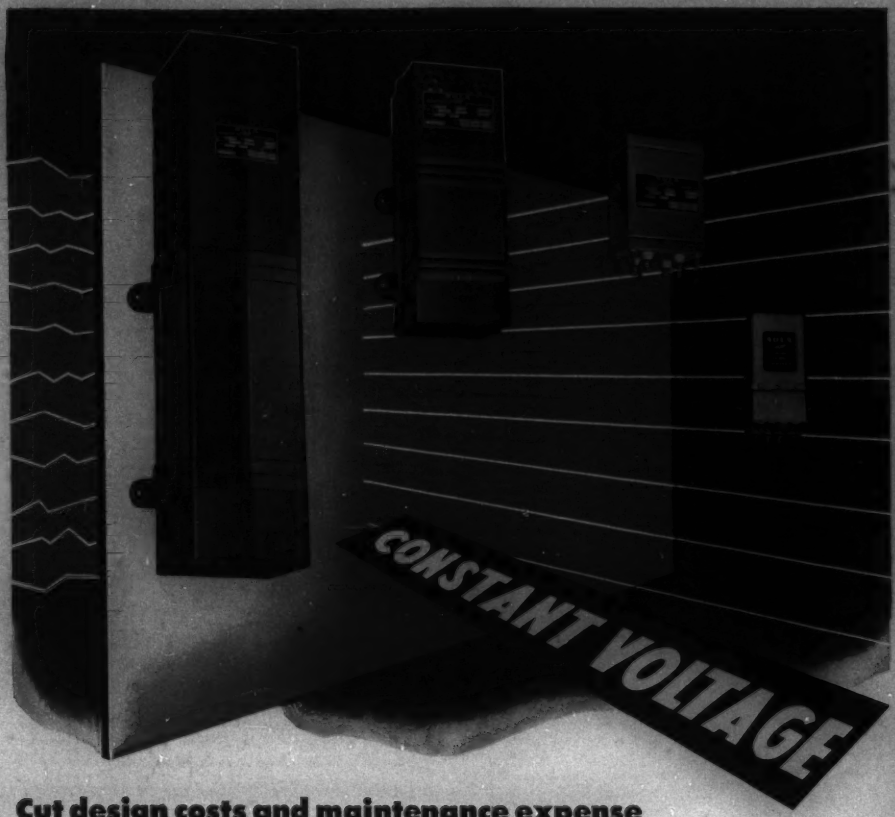

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HIGHLIGHTS.....

Great Lakes Meeting. As this issue goes to press, reports from Indianapolis, Ind., where this year's Great Lakes District meeting is being held, October 9–11, indicate registration of well over 250. Full details of the meeting will appear in the December issue.

Pacific Coast Meeting. Offering a well-balanced program of nine sessions, including a technical session on atomic power, the recent AIEE meeting at Seattle, Wash., attracted an attendance of 562, a record for Patific Coast meetings. Among the highlights of the meeting were an address on the "Development of Atomic Power" by Bruce R. Prentice, and a session devoted to a discussion of the organization of the engineering profession (*pages 529–31*).

John Frits Medal Awarded. Announcement has been made of the award of the John Fritz Medal for 1947 to Doctor Lewis Warrington Chubb (F '21) director of research in the research laboratories of the Westinghouse Electric Corporation, East Pittsburgh, Pa. Doctor Chubb was selected for his "pioneering genius and notable achievements during a long career devoted to the scientific advancement of the production and utilization of electric energy." The December issue of *Electrical Engineering* will have a further account of Doctor Chubb's career.

National Electronics Conference. Reports from the National Electonics Conference, meeting in Chicago, October 3 to 5, give the initial day's registration as exceeding 1,800. A full report of the 19 technical sessions of the conference will appear in the December issue.

Reactive Power Sign. Reader comment is invited on a proposition to change the sign of inductive reactive power from an arbitrarily accepted negative value to positive in order to provide a standard which will express the term "reactive power" as it generally is employed in engineering practice. Justification for the change is based on a report prepared by a subcommittee of the AIEE Standards committee (*pages 512–16*).

Industrial Hazard. The usefulness of X and gamma radiations in industry is partly offset by the hazard to workers engendered by the rays' "delayed-action" destructive effect on living tissue. Because it would be uneconomical if not impossible to make all industrial equipment employing the radiations absolutely foolproof, it is important that employees be provided with a set of supplementary rules to be obeyed for adequate protection (*pages 499–507*).

Science, Strength, Stability. Government by the people is really government by that portion of the people which takes the trouble to participate actively in the formation of public opinion. The engineer and the scientist, because of the specialized positions they, as professional men, hold in society, play a leading part in the development of that public opinion and so must accept their share of the responsibility for the enlightened world opinion which is a necessary condition for world peace (*pages 508–12*).

Development of the Saint Lawrence. Construction of a navigation channel 800 feet long and the development of 2,200,000 horsepower of hydroelectric capacity are two features of a proposed plan for the hydroelectric development of the Saint Lawrence River. The project, when completed, will provide power and navigation benefits for both the United States and Canada under terms of an agreement between the two nations for co-operation in its construction and maintenance (*pages 495–8*).

Human Progress. Although the increasing destructiveness of recent wars would seem to bode ill for the future of civilization, a survey of the progress of mankind since the era of Peking man still leaves room for optimism—that is, if man can learn to profit by the lessons of the past (*pages 521–2*).

Relays for Telegraphy. From an initial trial installation with a 3-link system from New York to Philadelphia, much progress has been made in the past year in the development of a radio relay system for domestic telegraphy. By materially reducing circuit interruptions resulting from storms, falling trees, and electrical disturbances, such a system is expected to improve the quality, dependability, and speed of telegraph service provided to the public (*pages 516–20*).

Automatic Calculator. The third and concluding part of an article describing the automatic sequence controlled calculator discusses the preparation and planning of the sequence control tapes. These tapes are employed when a large number of values is to be used by the calculator in a prescribed order. The values may be supplied to the machine via a perforated paper tape and one of the interpolator mechanisms to each of which three sequence codes have been assigned (*pages 522–8*).

Philosophy of Relaying. From a strictly objective point of view, the electric power system exists to render service to the customer better and more economically than he could be served by other methods. In spite of all precautions to assure excellence of service, however, the system still remains subject to unavoidable defects which result in faults that may damage equipment and interrupt service. Although relay protection cannot prevent these faults from occurring, it is a means of minimizing the effects of such faults when they do occur (*Transactions pages 735–47*).

Thermistors. The thermistor (or thermally sensitive resistor), a new circuit element made of solid semiconducting material, has characteristics of versatility and durability which make it especially adaptable for such applications as sensitive thermometers and temperature control elements, gas pressure gauges, and contactless time delay devices. Previously found impractical for widespread use because of a wide variation in the properties of units seemingly produced by the same process, the thermistor's present possibilities are the result of almost a century of research to overcome the device's imperfections (*Transactions pages 711–25*).

Military Communications. One of the major differences between the operation of a military communication system in the field and commercial operations is the method by which the requirements are limited with respect to the available supply of facilities. To develop a theater-wide system of communications with the complex operating features involved in a military setup, it soon was realized that staff responsibility without technical administrative authority over the operating personnel of the various subordinate command was entirely unsatisfactory (*Transactions pages 757–61*).

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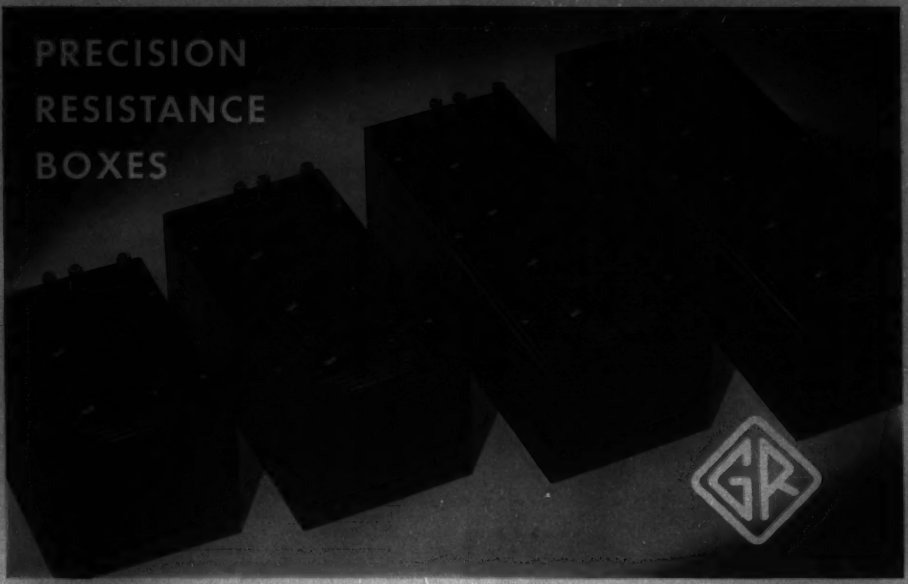

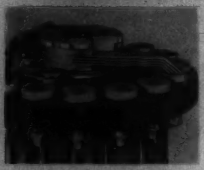

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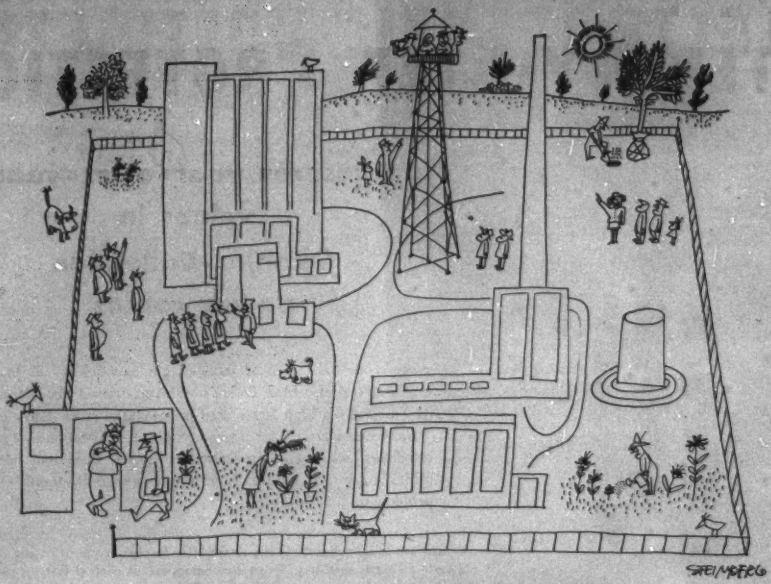

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Hydroelectric Development of the Saint Lawrence River

C. H. GIROUX
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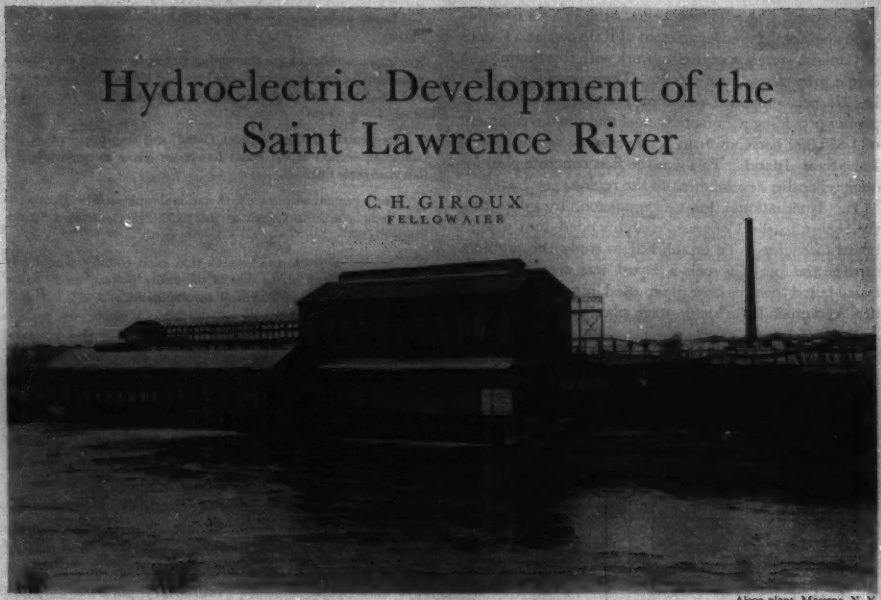

Alcoa plant, Massena, N. Y.

THAT STRETCH of the Saint Lawrence River between Ogdensburg and Saint Regis, N. Y., known as the "international rapids section" has been scrutinized with longing for many years by proponents of hydroelectric power and of navigation from the Great Lakes to the Atlantic Ocean, but to date very little has been done toward developing the potentialities which are existent in this region. There is a navigation canal on the Canadian side with a depth of 14 feet and with lock dimensions of 252 feet by 44 feet, far too small to accommodate the large bulk carriers used elsewhere in the Great Lakes System or seagoing vessels which now must end their journey up the Saint Lawrence River at Montreal, Quebec, Canada. Alternate routes from the Great Lakes to the sea, using the New York State Barge Canal and the Hudson River, or the Illinois and Mississippi Rivers, can accommodate vessels of even less draft than can the Canadian Canal.

Although that part of the Saint Lawrence River known as the "international rapids section" is potentially a promising source of hydroelectric power, little has been done thus far toward developing the region. However, a contemplated plan evolved jointly by Canada and the United States provides for improvement of the section for purposes of navigation and power.

Hydroelectric development in this vicinity consists solely of a relatively small plant belonging to the Saint Lawrence River Power Company, fed by a canal leaving the Saint Lawrence River at the head of the Long Sault Rapids and discharging into the Grasse River near Massena, N. Y.

HISTORY OF THE PROJECT

A brief review of the history of the work which has been done, leading up to the presently proposed comprehensive project, may be of interest and will provide a better understanding of the situation as it now stands.

In June 1909, by treaty between the United States and Canada, a permanent organization known as "The International Joint Commission" was created, having jurisdiction over matters pertaining to boundary waters between the two countries. This body did nothing about the project in question until 1919 when the Congress of the United States requested an investigation of the Saint Lawrence River between Lake Ontario and Montreal. As a result, Colonel W. P. Wooten, United

Essential substance of a paper presented at the Midwest Power Conference, Chicago, Ill., April 3–5, 1946.

C. H. Giroux is Special Assistant to the Chief of Engineers, United States Army, War Department, Washington, D. C.

States Army Corps of Engineers, and W. A. Bowden, chief engineer of the Department of Railways and Canals of Canada, were appointed to work with the commission in the preparation of a report. Their report, rendered in 1921, recommended a combined navigation and power project providing a 25-foot channel and the development of 1,850,000 horsepower in a powerhouse at the foot of Long Sault Island. This was the first concrete plan for comprehensive development of the region.

The International Joint Commission, in submitting the report to the Congress, recommended that a joint board of engineers be established to study the problem further and in 1926 such a board was created. This board failed to agree on a plan; the United States members recommended a single-stage plan, while the Canadian engineers recommended a two-stage development.[1]

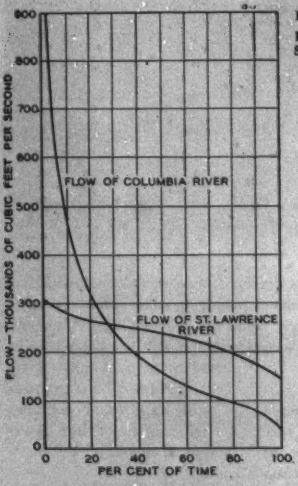

Figure 1. Comparison of flow of Saint Lawrence and Columbia Rivers

Subsequent to the foregoing, numerous reports were made and plans were proposed by Canadian and United States engineers culminating in the agreement of March 19, 1941, signed by representatives of the two countries, which provides for the construction of a complete project from the head of navigation on the Great Lakes to tidewater. The following are the principal features:

1. Equal division of water power in the rapids of Saint Mary's River.

2. Changes in the division of power now in effect at Niagara Falls.

3. Sole right of Canada to develop power in the Canadian section of the Saint Lawrence River.

4. Equal division of potential power in the international rapids section.

5. Improvements in the connecting waters between Lakes Huron and Superior and between Lakes Erie and Huron including a new lock at Sault Sainte Marie (since constructed by the United States Government).

6. Deepening of the Welland Canal and improvement of the Canadian section of the Saint Lawrence River to provide a 27-foot navigable channel.

7. Improvement within the international rapids section in accordance with a scheme known as the "238–242 Controlled Single-Stage Plan."

8. Division of work and cost so that each country would pay approximately half of the cost of the entire project, credit to be allowed for certain work already accomplished.

Further agreements were made by each of the governments providing for the operation of the power facilities and marketing of power by the Hydro-Electric Power Commission of Ontario and the New York State Power Authority. These agreements were incorporated in a bill which was not passed by Congress.

On October 16, 1940, the President of the United States issued an executive order establishing the Saint Lawrence Advisory Committee, consisting of representatives of the Federal Power Commission, Corps of Engineers, and New York State Power Authority, and directing the making of preliminary investigations and surveys and preparation of preliminary plans and specifications. In compliance with this order, the chief of engineers established the Saint Lawrence River District at Massena, N. Y., which, under the direction of Colonel A. B. Jones, and working in conjunction with the United States Advisory Commission, the corresponding Canadian committee, and other consultants, developed a project for improvement of the international rapids section of the Saint Lawrence River for navigation and power substantially in accordance with the previously mentioned controlled single-stage plan. This plan contemplates a navigation channel having a minimum depth of 27 feet with locks 800 feet long, 80 feet wide, and 30 feet deep over the sills. It also provides for the development of 2,200,000 horsepower of hydroelectric capacity. The subject matter which follows is based on the report prepared by the district engineer.

The project as recommended in the district engineer's report consists of the following principal features, supplemented by construction facilities; relocation of settlements, railways, and highways; navigation channel excavation, and dikes for the protection of certain property in the region which otherwise would be inundated by the power pool:

1. Iroquois Dam at Iroquois Point, to regulate the flow from Lake Ontario for the purposes of maintaining the lake level, and to aid in the formation of an ice cover in the winter season.

2. Point Rockway Canal and navigation lock to by-pass the Iroquois Dam.

3. Long Sault Canal and two navigation locks, by-passing the Long Sault Rapids.

4. Long Sault Dam at the head of Barnhart Island on the south channel of the Saint Lawrence River to create the power pool and to serve as a flood and emergency spillway for the pool.

5. Barnhart Island Dam and powerhouse at the foot of the island across the north channel of the river.

POWER POSSIBILITIES

From the standpoint of hydroelectric power, the Long Sault Rapids section of the Saint Lawrence River offers great possibilities because of the large regulated flow and the potential head which is available for development. Figure 1 gives a comparison of the flow of this river with that of the lower Columbia River, which illustrates the effect of the tremendous storage capacity of the Great Lakes on smoothing out the flow and thus enhancing the value of the water for power-generating purposes.

In order to obtain the full advantage of the potential head between Lake Ontario and the foot of the rapids, several schemes have been proposed in the past with one or more powerhouses in various locations, but the latest and most generally acceptable proposal is a single-stage project with the powerhouse located at the foot of Barnhart Island and development of a head which may vary from an extreme minimum of 71 feet to an extreme maximum of 87 feet. The normal head which was used for the design of the hydraulic equipment is 81 feet. Based on flow records extending over a period of about 80 years, it is computed that with this head and with the installation recommended, a firm capacity of 1,150,000 kw, firm annual energy of 10,110,000,000 kilowatt-hours, and average annual energy of 12,600,000,000 kilowatt-hours can be obtained at the site selected. Exhaustive studies of water utilization, cost, efficiency, space available, manufacturing facilities in the United States and Canada, and other considerations led to the conclusion that 36 generating units, each having a normal rating of 61,100 horsepower, will provide a well-balanced plant which will be practical, economical, and will make full use of the available resources.

The Harza Engineering Company, Chicago, Ill., was employed to make studies, estimates, and preliminary designs of the Barnhart Island powerhouse and related features. This company, under the general direction of the district engineer, and in collaboration with the advisory committee and other consultants, carried on the work which is described briefly in the following.

The powerhouse structure is 3,585 feet long and 180 feet wide, bisected transversely by the international boundary line. Starting at the center, each half includes one ice sluice at midstream, the powerhouse proper with one house service unit and 18 main units, and two more ice sluices at the shore end. Forebay level and downstream regulation is maintained by the operation of the spillway on Long Sault Dam, a separate structure at the head of Barnhart Island and on the south channel of the river.

The main turbines are of the Francis type designed to deliver 61,100 horsepower each at best gate and normal

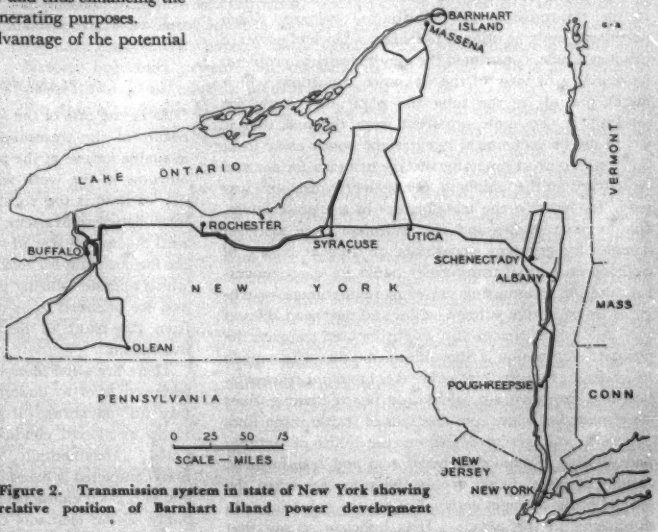

Figure 2. Transmission system in state of New York showing relative position of Barnhart Island power development

head of 81 feet; also 67,100 horsepower at full gate and the same head. The water capacity will be 7,200 cubic feet per second each at best gate, or a total of 259,000 cubic feet per second for the complete plant. Speeds of 69.2 rpm for the 60-cycle machines and 68.2 rpm for the 25-cycle machines were selected as giving specific speeds which would avoid objectionable cavitation and permit an economical generator design. The Francis type of runner was chosen in preference to the propeller type because of the higher permissible setting with less excavation which more than offsets the cost of higher speed generators which could be used with the propeller-type turbines.

The main generators on the United States side, and

six on the Canadian side, will be rated 55,000 kva at 95-per-cent power factor and will generate at 13.8 kv, 60 cycles. Due to the fact that a large part of the load of the Hydro-Electric Power Commission of Ontario is 25 cycles, 12 of the Canadian machines will be constructed for that frequency and rated 58,000 kva, 90-per-cent power factor. Generators are enclosed totally with integral air coolers but arranged so as to utilize the waste heat from them to augment the powerhouse heating system during the winter season.

Two units of 7,500 kva, 60 cycles, 13.8 kv, 80-per-cent power factor, 150 rpm, will be used to supply normal service for station auxiliaries, heating, and lighting.

POWER CONVEYANCE

The means for conveying power from the generators to the transmission and distribution systems, which necessarily must be utilized to market a block of power of this magnitude, constituted the major electrical problem, particularly in view of the unknown conditions which might prevail by the time the plant was ready for service. It was quite apparent from the first that it would not be economical to carry the power away from the powerhouse at generator voltage to a transformer and switchyard on the mainland, consequently provision was made for locating the transformers in the powerhouse. Innumerable studies and cost estimates were made of schemes for grouping generators on 13.8 kv busses, of utilizing individual transformer banks for each generator, and for transmitting power to high-voltage switchyards by both high voltage cables and overhead lines at such voltages as conceivably might be used to reach the ultimate destination. Short-circuit studies were made to determine required circuit breaker interrupting capacities, and extensive a-c calculating board investigations were made for many combinations of transmission lines of several voltages to determine the limits of stability and suitable reactance of generators and transformers. Results of these studies are available for use when the project again becomes active, but are too voluminous to summarize in this article. It is sufficient to say that feasible plans have been developed to meet almost any situation which may be existent when the project is built.

Figure 2 is a map of the transmission system within the state of New York as it existed at the time the report was prepared and the relative location of the plant at Barnhart Island. All of the major lines are nominal 110 kv, except for two running between the city of New York and Pleasant Valley which are 132 kv. The transmission system of the Hydro-Electric Power Commission of Ontario (not shown on the map) is partly 230 kv, 25 cycles, and partly 115 kv, 60 cycles.

The a-c calculating board studies of the Canadian system were made under the direction of representatives of the commission and were based on much more definite information than was available for the United States system. In studying the means for disposing of power generated on the United States side, many assumptions were made as to the amount of power which might be absorbed by industries in the nearby regions, the extent to which power might be utilized in the existing utility systems, and the requirements for long distance transmission to new markets or present heavy load centers. In this connection, the recommendations of the New York Power Authority and the Federal Power Commission largely were followed. The characteristics of existing transmission and generating facilities were obtained through the co-operation of the owning utility companies and utilized in conducting the studies. A comprehensive investigation of the limitations of a complete 115-kv transmission system with ties at Syracuse, Utica, Rotterdam, and Pleasant Valley was made, as well as of several combinations of 115-kv, 230-kv, and 287-kv lines.

PLANS FOR COMPLETION

As in the case of the facilities at the project itself, the results of the transmission line investigations will be available for use at the proper time. The only tangible outcome of the work which has been done along this line to date is the construction of 230-kv transmission lines between Massena and Taylorville, which were used during the war to supplement the power supply at the former point for making of aluminum. These lines, which operated during that time at 115 kv, are suitable and are intended to be used ultimately as main arteries from the plant to load centers which later will be established.

There are some features of the project which must be reviewed prior to undertaking construction in order to take full advantage of any new engineering developments or altered conditions since the report was prepared; fundamentally, however, the work which has been completed is based on sound engineering principles and is of such character and extent that construction of many of the elements can be started promptly upon authorization and the entire project can be carried to completion in accordance with an orderly program.

Inasmuch as the 1941 agreement between the governments of the United States and Canada has not been approved by the Congress, the project necessarily will be dormant until enabling legislation is passed. In order for the navigation facilities between Lake Ontario and the Atlantic Ocean to be effective, it also will be necessary for Canada to construct a suitable waterway below the international rapids on that part of the Saint Lawrence River which lies wholly within that country, as provided for in the afore-mentioned agreement.

REFERENCE

1. Senate document number 183, 69th Congress of the United States, second session.

Invisible Industrial Hazard

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With the growing use of X rays and gamma rays in the inspection of industrial products, it becomes increasingly important to acquaint both engineers and workers with the dangers to personnel engendered by the rays and with methods of protection from these dangers. Because of the "delayed-action" characteristics which render the radiations one of the most insidious of industrial hazards, safety measures must include not only preliminary protective barrier and distance factors, but must provide for periodic exposure tests and routine measurements of the dose of radiation to which a given worker is subjected.

X RAYS, AND GAMMA rays from radioactive materials, are increasingly common tools for the nondestructive inspection of industrial products. These radiations may injure workers seriously who are protected inadequately from them; their deleterious effects on the human body may be unsuspected for months or even years after exposure. Such an industrial hazard should be recognized by all engineers whose coworkers use these tools, as well as by the workers themselves. This article describes some of the properties of X rays and gamma rays and presents briefly the fundamental principles underlying the protection of workers from these radiations. It includes references to articles dealing with the specific practical methods of protection which have been devised and tested in industry.

There has been a very great acceleration during the past five years in the application of X rays, and of gamma rays from the radioactive products of radium, to the inspection of industrial products, and the increasing use of this powerful and useful method of inspection probably will continue. These highly penetrating radiations can be used to learn the presence or absence of defects within products of industry without destroying them. The inspection may proceed as a radiographic process which consists of the projection of a beam of radiation through the object to be inspected, and the recording of the shadows produced by the object on a piece of photographic film. This method provides an accurate and permanent record of the internal structure of the object. Alternatively, the X-ray shadow may be made visible by placing a fluorescent screen in place of the photographic film. In this case, the observer sees in a darkened room a pattern of shadows on the fluoroscopic screen, and he can perceive defects in the object by the proper interpretation of these shadows. This fluoroscopic method has the merit of being fast and economical, but it does not provide a permanent record. X rays also are being used increasingly in industry to study the crystalline structure of many industrial products. This is accomplished by means of X-ray diffraction apparatus.

The design and use of X-ray apparatus, and the use of radium in industry, have been accomplished by a relatively small number of specialists in this field. These specialists include metallurgists, physicists, chemists, engineers working for X-ray equipment manufacturers, X-ray technicians—many of whom have been trained in the medical field of radiology, and a few engineers in industry who are beginning now to learn about this new field of investigation.

Whenever X rays or gamma rays impinge upon living tissue, some cells of that tissue are destroyed. If the amount of radiation which traverses part of the human body is sufficiently small, no perceptible damage to the organism occurs. If the exposure is excessive, many painful and debilitating effects are produced. Many of the early workers who did not understand the destructive effects of X rays on living tissues suffered lengthy painful illnesses, disfigurement, and death.

At the present time there is adequate experimental evidence for the effective and economical protection of all workers in industry from these dangers. It is important that all engineers who may have to deal with the problems of installing and using X-ray equipment and radium in industry be informed properly of the dangers to personnel from these sources, and of the methods for minimizing these dangers.

EFFECTS OF RADIATION ON THE HUMAN BODY*

No precise description of the destruction of cells by X rays and gamma rays has been conceived. However,

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Figures 1 and 2 are reproduced by permission of Doctor Barton Young, Temple University Hospital, Philadelphia, Pa.; Figure 4 by permission of L. S. Taylor, G. Singer, and *Radiology* (volume 22, 1934, page 445); Figure 5 by permission of C. B. Braestrup[1]; and Figure 6 by permission of George Singer[2].

* The subject matter of this section represents conclusions reached by roentgenologists, biophysicists, and physicists from very extensive research. The author is indebted to Doctor Robert P. Barden, department of radiology, Hospital of the University of Pennsylvania, who read this section and suggested modification which have been incorporated.

there are strong implications that the radiation, assumed to be a stream of relatively high-energy quanta, causes ionization of atoms within the tissue; and that such ionization causes a change in the chemistry of the cell within which such ions are formed. In general, this change is destructive so that the cell subjected to ionization by X rays or gamma rays may die. Different kinds of cells react differently to the ionization produced by the rays. Thus, the cells that are damaged most by a given amount of radiation rays are the reproductive cells, while those that react least are the muscle tissues. Other parts of the body are affected in a manner intermediate to the effects produced upon these most and least sensitive tissues.

Figure 1. Excessive exposure during fluoroscopy 21 years before photograph was made

Although, as stated in the foregoing, the phenomena are not understood very clearly, it is agreed generally that the destructive effect of radiation upon tissue depends upon the amount of energy which is absorbed from the beam in the tissue. This opinion is the basis of a definition of the dose of X rays or gamma rays now internationally used in medical practice.

Small amounts of gamma or X rays do not cause sufficient destruction of cells to produce any known perceptible effect on the whole organism. Thus, protective measures need not have as an objective prevention of all such radiations from impinging on personnel, but only of reducing the amount to a specifiable minimum. However, it is not possible to reduce to zero the amount of radiation which falls upon a worker in the vicinity of X-ray apparatus or of radium.

THE PROTECTION PROBLEM

The problems of protection in the techniques of medical radiology have been analyzed carefully by radiologists and by physicists who have collaborated with these physicians. When X rays are used to make roentgenograms (X-ray films of parts of the human body) the amount of exposure never need be sufficient to produce a perceptible destructive effect. Thus, medical roentgenographic procedures supervised by competent roentgenologists and X-ray technicians are not dangerous. Neither is there great risk, under similar circumstances, of the patient's being injured by medical therapeutic radiation procedures. In these procedures the roentgenologist projects a gamma- or X-ray beam upon certain tissues which he hopes to destroy. At the same time he plans the treatment so that the destruction of nearby healthy tissue is not great enough to injure that normal tissue seriously. Furthermore, in medical practice so much attention has been paid to the problem of protection from radiation[1,2] that there need not be any danger to the roentgenologist, his technicians, or his patients.

The generalized and localized effects of excessive irradiation by X rays and gamma rays may be summarized as follows:

1. A preliminary decrease of the number of white cells in the blood followed by an accelerated and continued increase.[3,4]
2. Loss of hair.
3. Destruction of the metabolism of reproductive cells.
4. Production of "X-ray burns" which range from a simple nondestructive reddening of the skin to the production of an X-ray cancer or ulcer.

Figures 1 and 2 are examples of such deleterious effects. In both of these cases the insidious delayed action of these effects is demonstrated strikingly. The subject of Figure 1 was examined in 1925 by means of a fluoroscope. In this particular instrument it was apparently possible for the patient to be placed so that his skin was very close to the X-ray tube. Although the fluoroscopic examination probably proceeded normally, the patient's back was subjected to excessive radiation. Within a few weeks the back was reddened and sore. Now, 21 years later, the central portion of the lesion has become ulcerated, and the presence of malignant (cancerous) tissue is suspected. The patient who is the subject of Figure 2 underwent X-ray treatment for the removal of superfluous hair; treatment which

neither was recommended nor carried out by a physician. Twelve years later the disfigurement of the legs shown in Figure 2 became evident.

Such facts as these establish the necessity of installing adequate X-ray and gamma-ray protection; and of testing routinely to be sure that protection is effective. These points cannot be overemphasized.

PROPERTIES OF X RAYS AND GAMMA RAYS

X rays and gamma rays are streams of quanta* which traverse a vacuum without attenuation; their attenuations as they traverse various gases, liquids, and solids depend upon both the properties of the beams of radiation *and* the properties of the beams of radiation *and* the properties of the absorbing material. Certain properties of X rays can be specified usefully in each of several ways, two of which are:

1. Energy W of maximum-energy X-ray quantum: $W = 1.602 \times 10^{-19} V$ joules; V being the peak X-ray tube voltage in volts.

2. Minimum wave length λ $\lambda = \frac{12{,}395}{V}$ angstroms; V being the peak X-ray tube voltage in volts (1 angstrom $= 10^{-10}$ meter).

The energies of quanta of gamma rays commonly are measured by observing secondary effects produced when they interact with matter. It is inferred from such measurements that gamma rays are like X rays which would be produced by X-ray tube peak voltages up to approximately three megavolts.

The energies and the corresponding wave lengths of the quanta of a beam of X rays or gamma rays generally are spread over wide ranges. Relatively low-energy quanta are more likely to interact with matter than relatively high-energy quanta. Such interactions may occur in several ways:

1. The quanta may interact with atomic nuclei and thereby undergo a change in direction without a change in energy. Such quanta are called primary scattered quanta or rays, or unmodified scattering.

2. The quanta may impart to electrons all of their energies, thereby causing the electrons to be expelled from their parent atoms at velocities depending in each case upon the energy of the incident quantum and the energy required to separate the electron from the parent atom. Such events are called photoelectric absorption; the ejected electrons are called photoelectrons, and they have sufficient energy to cause the production of many more ions.

3. A quantum may impart to an electron a part of its energy, causing its ejection from its parent atom. In this case the quanta proceed with less energy (longer wave length) than they possessed as incident quanta. This process is called Compton scattering; the ejected electrons are called Compton electrons.

4. Quanta having energies greater than the energy corresponding to approximately 1,010 kv may be transformed into an electron and a positron, each having a velocity which depends upon the difference between the quantum energy and the energy (16.18×10^{-14} joules) corresponding to 1010 kv. This process is called pair production.

Each of the first three phenomena apparently occurs with both energy and mass unchanged before and after the event. On the other hand, in the fourth phenomenon radiant energy apparently is destroyed, and mass (the electron and the positron) are created. The theory of relativity correlates these facts. This theory leads to the conclusion that the "laws" of conservation of energy and conservation of mass should be considered as two approximations to a more general "law of conservation of mass-plus-energy." From this point of view, mass and energy are to be looked upon as two aspects of the same thing.

Figure 2. X-ray exposure for removal of excess hair 14 years before photograph was made

Initial exposure was not recommended nor carried out by a physician

The over-all effect of the phenomena that occur in the process of absorption is a reduction in the intensity of the beam of X rays or gamma rays, and a change in the spectrum, as the beam traverses matter; these

* A quantum is a specific amount of energy whose velocity in a vacuum is 2.998×10^8 meters per second. Beams of heat, light ultraviolet radiation, X rays, and gamma rays are streams of quanta.[4-11]

effects correspond to a loss of energy from the beam and most of this energy is lost as heat in the absorbing material. Some of the loss corresponds to the radiant energy of scattered radiation, ejected in all directions from the irradiated material.

The relatively high-energy quanta of an X-ray beam often qualitatively are called hard radiation. Such relatively hard radiation is attenuated less by a given thickness of a particular absorbing material than the relatively low-energy quanta which, in turn, are called soft radiation. Thus, the insertion of a filter (a sheet of metal) in a beam generally has the effect of absorbing more of the soft radiation than of the hard. Hence, the filtered beam is harder than the primary beam and more homogeneous.

Photoelectrons and Compton electrons cause, directly or indirectly, the production of many ions in the absorbing substance. For example, there may be several thousand ion pairs produced secondarily to the production of one photoelectron by the transformation of one quantum. When ions and electrons subsequently recombine, secondary X rays may be produced, characteristic of the substance which has been ionized. These secondary characteristic radiations are softer than the primary beam.[2,4,5]

The energy of a filtered X-ray beam or a filtered gamma-ray beam from an X-ray tube or from a radioactive material is not confined to a single wave length, that is, the beam is not homogeneous. Nevertheless, such beams approximate homogeneity closely enough so that the following properties of homogeneous beams are approximately valid for filtered beams. Homogeneous radiation undergoes an exponential decrease in intensity as the thickness of the absorber is increased. Thus, if x millimeters of a metal reduce the intensity of a homogeneous beam to one half of its initial intensity, $2x$ millimeters reduce it to one fourth of its initial intensity, $3x$ millimeters reduce it to one eighth, ... nx millimeters reduce the transmitted intensity to $1/2^n$ of its initial intensity. Quantitatively, the reduction per unit thickness is given by the linear absorption coefficient[2,4,5] which depends upon the wave length of the primary beam and upon the material. For a given wave length, the absorption coefficient is higher for elements of high atomic number than for elements of low atomic number (examples are given in Table I).

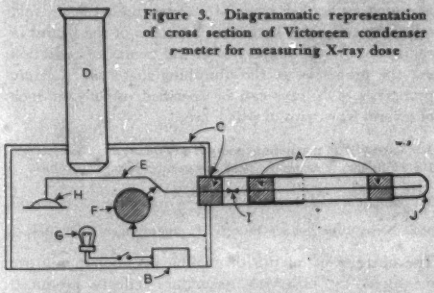
These theoretical points are introduced because they are fundamental to the measurement of the properties of the radiation which are of practical interest and to the accurate determination of adequate means of protection from unwanted radiation.

MEASUREMENTS

The theories from which the foregoing outline has been abstracted are based upon fundamental experiments. These experiments on X-ray beams and gamma-ray beams often are concerned with indirect methods of measuring energy, and energy per unit area per unit time—which is called intensity. These experiments are difficult to perform. They are not adaptable to the practical problems of measurement in industrial and medical radiology.

Practical measuring systems in this field conveniently are based upon relatively gross effects of radiation such as the production of ionization in gases, the darkening of photographic film, or the production of light by fluorescent materials. All three effects are used to control radiologic processes and all three effects are used to measure the effectiveness of protective measures.

Figure 3. Diagrammatic representation of cross section of Victoreen condenser r-meter for measuring X-ray dose



A—Amber bushings
B—Flashlight battery
C—Lead shielding and chromium-plated steel case
D—Eyepiece
E—Metallized quartz fiber
F—Frictional device
G—Lamp
H—Quartz bow support for fiber, E
I—Contact
J—Chamber

Measurements based upon the ionization of gases are taken as practical standards, because these measurements can be reproduced relatively easily with an accuracy of plus or minus two per cent with generally available portable apparatus. Such ionization-measuring devices have been constructed in several forms. One of the most commonly used secondary standard instruments is the Victoreen condenser r-meter, the structure of which is shown in Figure 3. The chamber J is at the end of a metal tube which can be fitted into the socket at the end of the electrometer case. The case and tube are metalclad and are shielded with lead. The chamber itself is made of bakelite, and its inner surface is coated with graphite, which is connected electrically to the metal case C of the instrument. The second electrode of the chamber is an axial wire insulated by means of amber bushings A. When the chamber tube is inserted in the measuring instrument, the axial electrode is connected to the string of the electrometer by the contact I.

Within the case of the measuring instrument is a flashlight battery B and a lamp G which is lighted by pressing the switch in the side of the case. The lamp

illuminates the metallized quartz fiber *E*, and its deflection can be observed through the eyepiece *D* which contains a calibrated scale. In order to use the device, the chamber tube is inserted in the measuring instrument and a knob on the side of the case is pushed toward the case and rotated. This causes a frictional device *F* to be rubbed against a contact; the result is that the string *E* and the axial electrode of the chamber are charged with respect to the case and the outer electrode of the chamber. The total capacitance of the instrument is approximately 50 micromicrofarads. When the device is charged fully the difference of potential between two electrodes of the chamber is approximately 400 volts. Under these conditions, the image of the string appears at zero on the scale.

When X rays traverse the chamber, which contains air at ambient temperature and pressure, electrons are knocked out and positive ions are formed. The electrons are attracted to one electrode, and the ions are attracted to the other electrode. This decreases the difference of potential and causes a change in the deflection of the fiber which can be observed by means of the eyepiece and scale.

The scale of the instrument is calibrated in roentgens. This unit is defined as follows:

> The roentgen shall be the quantity of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air, produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

The mass, 0.001293 gram, is the mass of one cubic centimeter of dry air at zero degrees centigrade and 760 millimeters of mercury pressure. Thus, if the instrument is calibrated in roentgens at a particular temperature and pressure (usually 20 degrees centigrade and 760 millimeters of mercury pressure) a correction must be applied to the reading for other temperatures and pressures. Although this definition of a unit of measure appears complicated, it is based upon careful analysis and test over a period of 40 years, and it now is accepted as an international standard. The unit has several important advantages. For example, the Victoreen condenser *r*-meter integrates the quantity or dose which it measures; that is, one measurement may produce a reading of 20 roentgens in two minutes while another measurement may produce a reading of 20 roentgens in four minutes. Although the doses in the two cases are equal, the dose rate in the first case is ten roentgens per minute, while the dose rate in the second case is five roentgens per minute. A second advantage is that the measurement is made in air so that measurements can be made either with no material interposed between the source of X rays and the chamber, or with various materials interposed. A third advantage is that the measurement disturbs the beam relatively slightly inasmuch as the energy absorbed by such a chamber is usually a minute fraction of the beam's total energy.

This measurement of quantity of X rays or dose often is used as a basis for the measurement of the quality or penetrating power of a beam. To make such a measurement the chamber is placed at a convenient distance from the X-ray tube and filters are placed successively over the window of the tube. Readings of the ionization chamber plotted against thickness of filter constitutes an absorption curve which is a clue to the quality or penetrating power of the radiation. It is common practice to plot as the ordinates of such curves the

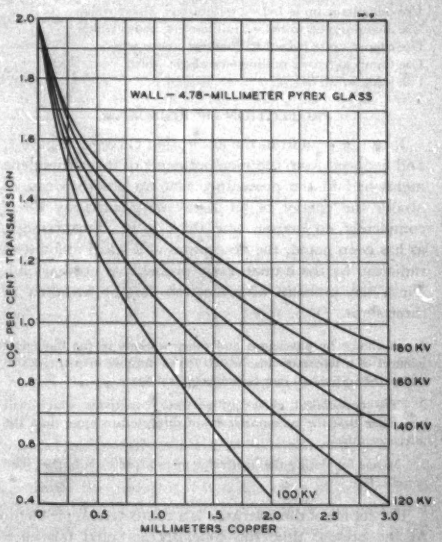


Figure 4. Logarithmic absorption curves in copper

logarithm of 100 times the ratio of the reading with no filter to the reading with a particular added filter. The result is a logarithmic absorption curve, examples of which are shown in Figure 4. These particular curves show clearly that the radiation from a constant potential apparatus is attentuated far more greatly by a given thickness of copper when the tube voltage is 100 kv than it is attenuated when the tube voltage is 180 kv.

It is often convenient to specify by a single number the penetrating power of a beam of radiation. By common consent the number which is used for this purpose is the half-value-layer. For example, from the 180-kv curve of Figure 4, the logarithm of the per cent transmission through a filter of 0.50 millimeter of copper is approximately 1.535. The thickness of copper which will reduce the dose rate to one half is that thickness which reduces the logarithm of the per cent transmission

by 0.301 (= log 2). The logarithm per cent transmission for 1.40 millimeters of copper is 1.234. Thus, the half-value-layer for 180-kv radiation emitted through a 0.50-millimeter copper filter is 1.40 − 0.50 = 0.90 millimeter of copper.

The material which conventionally is used for measuring half-value-layer varies with the quality of the radiation. The following limits and filter materials are recommended by the standardization committee of the Radiological Society of North America:[8]

For qualities measured in hvl (half-value-layer)—
Use cellophane up to hvl = 2 millimeters, above which
Use aluminum up to hvl = 2 millimeters, above which
Use copper up to hvl = 2 millimeters, above which
Use tin up to hvl = 2 millimeters, above which
Use lead, for all hvl.

PROTECTION OF PERSONNEL

It can be seen from the absorption curves of Figure 4, and deduced from the measurements of the phenomena mentioned in the preceding, that an absorber cannot absorb the energy of an X-ray or gamma-ray beam completely no matter how thick it is. Furthermore, as has been noted, the absorption of a small amount of radiation by the human body probably is not harmful. Thus, the problem of protection can be attacked in three steps:

1. A choice by physicians and other workers in the biological sciences of a tolerance dose which is the number of roentgens to which the individual can be subjected safely.

2. The economical choice of protective methods which will guarantee that the personnel are not subjected to more than the tolerance dose.

3. Means for testing the protective methods to be sure that they are effective.

The choice of the tolerance is a controversial problem. At the present time the generally accepted tolerance dose is 10^{-5} roentgen per second for a 7-hour daily exposure if the worker has a month's vacation each year. Some biophysicists allege that this tolerance dose is too high, and they recommend that it be reduced by a factor of 10. In spite of these criticisms the larger amount (10^{-5} roentgen per second) generally is used at the present time. A commonly discussed intermediate tolerance dose is 0.1 roentgen per day which is somewhat less than the rate 10^{-6} roentgen per second; both being considered in relation to a 7-hour working day. Incidentally, the rate of the 10^{-6} roentgen per second is approximately 10,000 times the dose rate attributable to cosmic rays.

Table I. Examples of Linear Absorption Coefficient

$I = I_0 e^{-\mu x}$; I_0 Is the Initial Intensity, I Is the Intensity Through a Thickness x Centimeters of a Material Whose Linear Absorption Coefficient Is μ Centimeters^{-1} for the Wave Length Specified

Absorber	Linear Absorption Coefficient	
	λ = 0.63 Angstrom	λ = 0.098 Angstrom
Carbon	1.05	0.32
Copper	322	2.89
Lead	1,078	38.5

Committee Z 54 of the American Standards Association in preparing a "War Standard" Safety Code for the industrial use of X rays and gamma rays agreed upon a permissible daily dose of 0.1 roentgen.[10]

The problems of choosing protective methods which will assure that the operators of industrial radiation equipment will be subjected to less than the tolerance dose are quite complicated, and relatively few workers at the present time are competent to devise such protective methods. The following will outline some of the principles which are involved but will not attempt to present detailed methods for working out plans for protection.

Two fundamental principles to be applied to the problem of protection are:

1. As much protection as possible should be provided as near the source as possible.

2. While exposures are being made, every worker should be placed as far as possible from the source of radiation and from material upon which the radiation falls.

The two factors which are most economical in providing adequate protection are the distance from the source, and the insertion of lead, concrete, or other absorbing material so that it will absorb a large part of the radiation which otherwise would strike the worker. The factor of distance cannot be overemphasized. The radiation from a source decreases inversely as the square of the distance from the source. Thus, to give a specific example, if the operator is situated so that he is subjected to irradiation at the rate of 4×10^{-5} roentgen per second, it is possible that he can be protected adequately if his position is changed to one which is twice as far from the source as his original position. Although such a simple case as this is not likely to occur in practice, it is an excellent example of economical protection which occasionally can be provided by distance alone.

Of the protective materials, lead is the most effective practical material per unit thickness at 400 kv peak or less. The dose rate for filtered 200-kv-peak X rays can be reduced by a factor of 1,000 by an addition of approximately 3 millimeters of lead; at 400 kv approximately 12 millimeters of lead would be required to produce the same reduction in dose rate. However, as the required thickness of lead becomes greater than about one half inch, it becomes increasingly expensive to buy and to install. Therefore, for extremely high voltages and for gamma-rays very often it is economical to use concrete even though the thickness of concrete is greater by a factor of the order of 15 than the thickness of lead required to produce the same ab-

sorption. A general inference would be, therefore, that up to 400 to 500 kv peak, lead would be used as the protective material; while from 500 kv peak upward, concrete may be expected to be the more economical material. It must be emphasized, however, that great care in the installation of concrete must be exercised. For example, suitable kinds of concrete building blocks may be used only if the cracks between blocks are plugged properly with cement so that the absorption between these bodies is equivalent to the absorption through the blocks themselves. Of particular value for learning the details of measurements in this field are articles by C. B. Braestrup and L. S. Taylor.[9,10]

Throughout this field of investigation there are relatively few experimental data particularly for X-ray tube voltages higher than 400 kv peak. For this reason three sets of data are reproduced from the afore-mentioned articles. The first, Figure 5, is a chart from Braestrup's article.[9] This chart is a compact summary of information concerning how much lead protection is required in various circumstances likely to be encountered in practice. Information derived from the chart, in the form of a thickness of lead, is likely to provide a factor of safety, for various reasons to be discussed. Three numbers are required to "enter" the chart:

1. Either the total milliampere-minutes of exposure for a day of 8.3 hours or the X-ray tube current in milliamperes.
2. The distance of the operator or other worker from the X-ray tube, in meters or feet.
3. The X-ray tube peak voltage in kilovolt peak.

From these three numbers, the chart can be used to find that thickness of lead which should be inserted between the operator or other worker and the apparatus which will reduce the dose to him to less than 0.1 roentgen per day. For example, if the X-ray tube current is 10 milliamperes, the distance from operator to tube is 16 feet, and the X-ray tube voltage is 250 kv peak, proceed as follows. Find the diagonal line whose intersection with the ordinate scale on the left is marked 5,000/10; this diagonal line represents exposure of 5,000 milliampere-minutes, or continuous operation during an 8.3-hour day at 10 milliamperes. Next, find the diagonal line whose intersection with the ordinate scale on the right is marked 5/16; this diagonal line represents a distance from operator to tube of 5 meters (≈ 16 feet). Follow these diagonal lines to the point of their intersection, then proceed vertically to the curve marked "250 kv peak"; the thickness of lead horizontally opposite to this point, on the scale of ordinates, is the required thickness of lead. In this example the result is 6.2 millimeters of lead. Note that, if 10 milliamperes 250 kv peak is the maximum rating of the X-ray apparatus, protection by 6.2 millimeters of lead is likely to exceed the requirement because it is unlikely that the equipment will be operated continuously at full rating.

Table II.* X-Ray Protection Required to Reduce the Direct Radiation to 0.1 Roentgen Per Day

Protection Is Given for Different Exposures Per Day Indicated in Milliampere-Minutes and Corresponding Milliamperages for Continuous Operation

Distance		400 Kv								1,000 Kv							
		1,500 Ma-Min (3 Ma)				2,500 Ma-Min (5 Ma)				500 Ma-Min (1 Ma)				1,500 Ma-Min (3 Ma)			
	Feet	Lead		Concrete		Lead		Concrete		Lead		Concrete		Lead		Concrete	
Meters (Approximate)		Mm	In.	Cm	In.	Mm	In.	Cm	In.	Mm	In.	Cm	In.	Mm	In.	Cm	In.
1	3	17.5	11/16	30	11 3/4	18.5	3/4	31	12 1/4								
2	7	14.9	9/16	26	10 1/4	15.8	5/8	27	10 5/8			88	35			105	41
3	10	13.4	17/32	24	9 1/2	14.3	9/16	25	9 7/8			77	30			93	37
4	13	12.2	15/32	22	8 1/2	13.2	17/32	23	9 1/16			68	27			84	33
5	16	11.3	7/16	21	8	12.4	1/2	22	8 5/8			63	25			78	31
6	20	10.7	13/32	20	7 1/4	11.7	15/32	21	8 1/4	73	2 7/8	58	23			73	29
8	26	9.6	3/8	18	7	10.5	13/32	19	7 1/2	67	2 1/2	52	21			65	26
10	33	8.7	11/32	17	6 3/4	9.7	3/8	18	7 1/16	63	2 1/2	46	18	73	2 7/8	58	23
20	66	6.1	1/4	13	5 1/16	7.1	9/32	15	5 7/8	49	2			60	2 3/8	43	17
30	98	4.6	3/16	11	4 1/4	5.5	7/32	12	4 3/4	41	1 5/8			52	2		
40	131	3.5	1/8	9	3 1/2	4.4	5/32	10	4	35	1 3/8			46	1 7/8		
50	164	2.7	1/8	7	2 3/4	3.6	1/8	9	3 1/2	30	1 1/4			41	1 5/8		

* Reproduced by permission of C. B. Braestrup.[9]

TUBE SHIELDING

It has been noted that economical protection includes lead near the X-ray tube. In most modern apparatus the X-ray tubes are covered by a grounded metal shield; lead is incorporated within this shield. Thus a beam of high dose rate is emitted only from a port provided for the primary radiographic beam. If this beam always is made as small as possible by means of a lead diaphragm or lead-lined cone, and if the primary beam always falls on the object to be radiographed, it is practically impossible for the operator or other worker to be in the path of the direct beam for which the protective thickness of lead derived from Figure 4 would be required. However, if less lead is used, there is danger that the equipment may be operated with no absorbing object in the direct beam, thereby endangering the

personnel. Inasmuch as such errors in operation can occur, the most conservative protective measures are to be recommended.

The second, Figure 6, is a chart from Taylor's article[10] which provides information on the use of concrete as

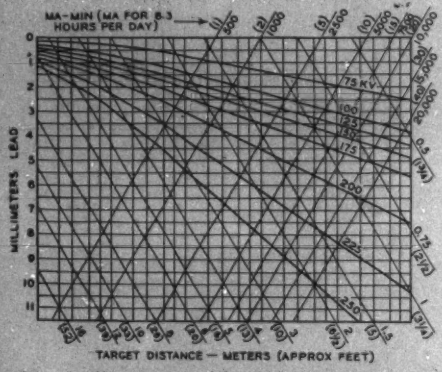


Figure 5. Chart for determining thickness of lead required to reduce dose rate to 0.1 roentgen per day if kilovolt peak, milliamperes-minutes, and distance are known

protective material. The data for this chart were derived from extensive measurements described in detail in a publication of the United States Bureau of Standards.[11]

The third item, Table II, is reproduced from Braestrup's article.[9] The data of this table are thicknesses of lead or concrete required at 400 kv peak and 1,000 kv peak for adequate protection at various distances. These data supplement the data of Figure 5.

ERRORS IN PROTECTION DESIGN

Although shielding from the direct beam is the most important problem of protection, errors in designing protection occur most often because of failure to deduce the path of scattered radiation. For example, an operating booth well protected on the four vertical sides is little more than a trap if scattered radiation enters through the top or bottom of the booth. On the other hand, it is unlikely that the top and bottom of such a booth or some of the vertical sides need contain as thick lead as one or two of the vertical sides which may be subjected to the greatest exposure. Thus the problem of providing protection which is at once safe and economical is seldom a simple problem.

The protection of outside walls requires special consideration. If no one works outside such a wall at distances such that the exposure is greater than 10^{-4} roentgen per second, no protective barrier need be used, with one possible exception. The exception is: if the radiation through a wall irradiates a scattering object so placed that scattered radiation from it may expose workers excessively, the wall, or at least a part of it, must be shielded by lead or other absorbing material.

Protection from gamma rays is accomplished far more economically by distance than by protective barriers. The attenuation of filtered gamma rays in lead is approximately one half for a thickness of one centimeter. Therefore, only very thick and expensive lead barriers would be effective; such thicknesses, for various amounts of radium, are given in a chart in a handbook of the Bureau of Standards.[2] Radium should be stored in a safe having within it a lead case no thinner than five centimeters in which the radium is placed. It should be carried in such a way that it is surrounded at all times by several centimeters of lead and in such a way that it is never nearer than one meter to the person who is carrying it. Tubes containing radium should be moved by means of forceps, and there should be a lead barrier five centimeters thick between the operator and the tube.

MEASURING SAFETY

The installation of protective measures marks the beginning, not the end, of the prevention of excessive exposure of workers to X rays and gamma rays. Regularly repeated tests of the exposure of workers are necessary. Complete blood counts on all who work regularly near X-ray apparatus or radium should be made every two months[1] and approximate measurements of the X-ray or gamma-ray dose to which each worker is subjected should be made routinely.

Although normal, dark-adapted eyes can perceive the illumination of a fluoroscopic screen which is subjected to X rays with a dose rate of the order of 10^{-6} roentgen per second, this method seldom is used to make routine tests of protective barriers. The fluoroscopic method has two disadvantages for routine testing: the results are not quantitatively accurate; and the method measures dose rate rather than dose (integrated). Nevertheless, a piece of fluoroscopic screen is useful to spot-check a protective installation; particularly to test for leakage through cracks in walls or around the edges of lead-lined doors.

The Geiger-Müller counter is also a very sensitive radiation detector. It has approximately the same disadvantages, and the same field of usefulness as the fluoroscopic screen. Recently designed counters are calibrated in microroentgens per second; increasing use of these new devices may be expected.

Convenient and satisfactory tests can be made by means of dental X-ray films. A strip of lead about 1/8-inch wide by 1/16-inch thick, or a paper clip, is fastened on both sides of the film packet, which is light-tight. This combination is carried by a worker for

several days, and the film then is processed. The approximate exposure in roentgens can be determined by comparing the density of the test film with the density of a similar film exposed in a beam of known dose rate for a known time. If the shadow of the lead strip or paper clip is imperceptible, the bearer of the packet has not been exposed excessively to X rays.

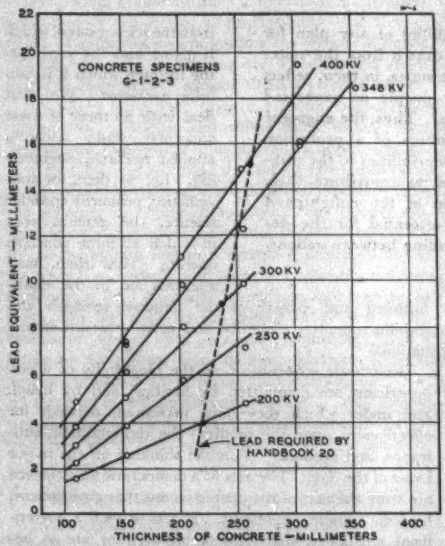


Figure 6. Thickness of poured concrete required to provide same protection as lead

The most satisfactory method for measuring the radiation to which a worker is exposed is for him to wear a calibrated ionization chamber throughout a working day, and to measure in roentgens the daily exposure. There is available for this purpose an electrometer and charging device operable from a 110-volt 60-cycle source and as many chambers, each having the appearance of a fountain pen, as may be needed. Each chamber can be charged, and carried by a worker for one day. At the end of the day, each chamber is inserted into the electrometer to measure the total exposure, in roentgens, to which it has been subjected. The full-scale reading is 0.1 roentgen.

CONCLUSION

The "delayed action" of X rays and gamma rays as destroyers of living tissue render these useful radiations one of the most insidious of industrial hazards. As it would be uneconomical, if not impossible, to provide perfect protection to all workers from these hazards, practical industrial radiographic, fluoroscopic, and diffraction installations are not foolproof. If they are designed well and installed competently, such installations may be safe if supplementary rules are specified and obeyed by all workers. Some of the points to be considered in formulating such rules are:

1. Never subject any part of the human body to the direct beam from an X-ray tube or radioactive material.
2. Never assume that a worker is safe; always measure the radiation at his location under regular operating conditions.
3. Never operate an X-ray tube without an absorbing object in front of it.
4. Never permit a worker to be in the path of the primary beam from an X-ray tube, even if an absorbing object is placed between him and the tube.
5. Always remember that radiation may scatter around the edges of a vertical protective barrier.
6. Never touch a radium container and never place one in the pocket of a piece of clothing.
7. Make routine blood tests and physical examinations of workers.
8. Make routine tests to prove that the protection and the operating rules are effective.
9. Provide 4-week vacations for X-ray and radium workers.
10. Report the results of tests to employees in order to emphasize both the need for vigilance and the reward for it.

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Science, Strength, and Stability

VANNEVAR BUSH
FELLOW AIEE

The strength and stability of any plan for world peace must be drawn from the states composing it and these states, in turn, reflect the thinking of their people as expressed through public opinion. Thus, the engineer and scientist, as members of a profession with its attendant responsibilities to the public, must be prepared to contribute their share to the formation of the enlightened world opinion that is essential for the development of understanding between nations.

THE international peace which is demanded by thoughtful men the world around is not the mere absence of war. It is something far more positive than that—it is a condition of amity and cordial collaboration among independent national groups, each confident in its own vigor, within an international framework. It thus is dynamic, not static; progressive, not stagnant; pioneering in all fields where general betterment of man's spiritual and material life may be expected. We have not had it for many a long year. We do not have it now. Yet we know that it must be secured if the human race is to continue, and we have faith that ultimately it can and will be assured.

But faith without work is not enough. For the boon of this peace to be attained, and for the heart-rending scourges of destruction, disease, famine, and despair to be lifted throughout the world, there is work, much and great work, to be done. It is only as all types and conditions of men do their share unselfishly that there can be created in each of the peoples of the world the self-confident vigor which is the essential precursor of unstinted world collaboration. Whatever the ultimate world system toward which we are tending, whatever may be surrendered of individual sovereignty by the nations in the interest of that system, its strength and stability will have to be drawn from the several states composing it. Recognizing this imperative condition, we recognize that the first task laid on every group in America's wonderfully varied population is for each group to give, seriously and consciously, its best effort toward the creation—and the enhancement—of strength and stability in the United States.

TECHNOLOGY AND PEACE

We are concerned, in this article, with the general subject of technology and international peace. What is technology? As contemplated here, it cannot be regarded in isolation. It cannot be considered apart from the science out of which it grows and the engineering through which it is usefully expressed. We must deal with all three of these concepts; basic research, applied research, engineering. Let us then, for convenience, primarily consider science, the general area in which all three concepts operate. How then, may scientists aid in the establishment and growth of the national strength and stability essential to amity and active concord among nations?

Democratic government, to the philosophy of which Americans are committed by heritage and by belief, and under which they have prospered, depends for effectiveness upon the quality—the thoroughness, substance, and keenness—of public thinking on the major issues of the day. The acts of a democratic government are truly the acts of the people whom that government, by their consent, represents. If acts of such a government are faulty, shortsighted, unjust, they are so because the people have been heedless, selfish, unthinking; and those faulty acts will stand uncorrected until such time as the people are roused from lethargy to serious thought which will crystallize in better action.

Public thinking which comes to expression in government action is the product of two forces. One of these, like the sparks over a lava flow, is spectacular and dramatic. It is the force exerted by the extreme pressure group, rallied for specific action on an immediate issue or marshaled for continued agitation in support of some special interest. At times it can extend to coercing government while working lawfully within the frame of government. It is essentially direct action for self-interest. Not all direct action, fortunately, is of this kind; men can apply their energy and their skill directly to public problems with no self-seeking, and men do, as we all know. There is need of more suchmen.

The second force in the formation of public opinion, like the lava flow itself, moves more slowly and with far less superficial drama. It is a vast force, and in the end produces fundamental change. This is the force that operates through the long-term development of matured public opinion by the gradual influence of enlightened and disinterested citizens. Government

Essential substance of an address presented at a symposium on "The Technology of International Peace," Walker Memorial, Massachusetts Institute of Technology, Cambridge, Mass., June 8, 1946.

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by the people is really government by that portion of the people which takes the trouble to participate actively in the forming of public opinion. It is this fact which explains the feeling of responsibility for discussion of public questions and for sincere consideration of them—the feeling that every thoughtful man has experienced.

Professional groups in the United States particularly are aware of this feeling of responsibility—this duty—to take a conscious part in guiding the growth of public opinion and thus in shaping the forces which result finally in governmental action. This is a serious matter; it is no light thing for a man or a group to undertake deliberately to evoke and direct such forces. But professional men realize that theirs is a special obligation, for they must recognize that they, in their education and professional training, have benefited especially from the existence of organized society. They realize, too, that they stand in a unique relationship to other groups in the population and in a unique relationship to the population as a whole, and that the implications of that relationship are extremely important, not merely to them, but far more to the people in general. This realization always has rendered professional groups reluctant to plunge into militant partisan political action, for fear of jeopardizing that relationship. Yet, by acceding to this requirement for caution, they impose uneasiness upon themselves, for the recognized obligation—the social debt—still stands, and they are concerned over it.

THE PROFESSIONS AND PUBLIC OPINION

To understand what this unique and socially valuable relationship is, and whence it comes, both defines the idea of a profession and explains the origin of the professional man's concern over the question of how and how much he shall participate in the formation of public opinion. The hallmark of a profession is ministry to the people; the disinterested and authoritative employment of special or superior knowledge for the counseling and the safeguarding of others. Ministry in this sense is much more than service; it is marked by ideas of dignity and authority, especially the authority arising from special training, special competence, or high ethical conduct. Ministry is performed when one who has become adept in higher knowledge through his devotion and study draws upon that knowledge authoritatively for the benefit of other people. That the idea of ministry is accepted by the people needs no demonstration; their acceptance of it is signalized by the prerogatives which the professional man is allowed to maintain, by his distinctive place in society, which is his because the people have reason for confidence in the integrity of his profession and for belief in its general beneficence.

That confidence and that belief are derived in some measure from the public's respect for the body of knowledge in which a professional group is adept and which it administers; a respect based both on the fact that the knowledge is personally valuable to the individual citizen and on the fact that the dignity of tradition and long heritage clings to it. In larger measure, however, the confidence and belief of the public in the beneficence of a profession are based on the fact that in their ministry of the people the members of that profession are disinterested, seeking first and foremost only to perform their ministry honestly and ably as required by their self-imposed code of ethics. This statement does not imply that ministry inevitably demands a vow of poverty. If he is to be truly effective, the professional man properly may insist that he receive for his work a material return adequate to keep his mind free for full and effective performance. But his interest in material return is secondary. If it becomes primary, he ceases to be a professional man.

Inasmuch as the authority and dignity which the professional man must have for the full performance of his professional function rely so heavily upon the fact that he is recognized as free of a controlling self-interest, it is natural enough that he should weigh carefully the matter of participation in political affairs. If he compromises his disinterestedness, he risks prejudicing his ministry. And he knows the importance to the people that that ministry be not prejudiced. At the same time, he cannot but recognize that the disinterestedness of the professions often can supply a highly needed balance wheel in social mechanisms, and that very often the authority of the professions in their own callings may lead the people to look to them for sound counsel on other matters.

For emphasis, I have set this dilemma out in large and plain terms, taking the hazard of overstating it in order to gain the advantage of putting it bluntly. We know that professional groups sometimes resolve it, for we know that they can and do contribute to strength and stability in government by directly sharing in and influencing the public thought on which these depend. On some occasions they have done so at no inconsiderable risk to their unique relationship to society, yet I believe that even that risk usually can be avoided. It is instructive to review summarily the general course which some of these groups have followed.

CONTRIBUTIONS OF THE PROFESSIONS

The clergy, whose position as a professional group is most clearly a consequence of ministry to the people, for centuries have contributed to governmental vigor by their influence as a profession quite apart from their most profound personal influence as men of God. More and more in recent times they have taken the route of direct action, with all that implies of committees, petitions, signatures on manifestoes, and other activities, very often having to do with issues most remote from the professional competence of the individuals involved. In all likelihood, however, the vital effectiveness of the

clergy in raising the general moral tone of the public mind, in increasing our responsiveness to humane values, has come in greater measure from the long-range indirect influence which is characteristic of true ministry, and there is serious question within the profession itself whether the superposition of direct activities is worth what it costs. In fact, this question is as old as organized religion itself.

The profession of medicine, with its long and distinguished history, its high degree of organization, and its unique code of professional conduct epitomized in the time-honored Hippocratic Oath and vigorously maintained by the traditions of the profession, had and has great power and influence. We have seen sweeping changes in public thinking about sanitation, public health, and similar matters in the past century. Yet it is only a little more than 100 years ago that Doctor Benjamin Waterhouse, in Cambridge, Mass., was but a voice crying in the wilderness. The enlightenment that has come in the century since his time is testimony to the force which medical men have exerted. They have contributed greatly, as individuals and as a professional group, to the development of a public responsiveness and receptiveness that not merely accepts but actively demands legislation unthinkable 100 years ago. In the main, moreover, the profession of medicine has secured these and other good results not by short-range direct action, but rather by its long-range influence on the public mind.

Resembling medical men in their holding of a particularly specialized place in the community, in their firm and comprehensive organization, and in their administration of self-imposed standards of professional conduct, lawyers as a profession are set apart by the fact that in a government which is of laws and not of men they stand, necessarily, in a special relation to public affairs. So much of the lawyer's work is done in terms of immediate issues, so many demands are imposed on him by the day-to-day hurly-burly, that it is easy for men outside the profession, and indeed, for some lawyers themselves, to lose sight of the core of knowledge and ministry that renders the law a profession in the real sense. For the same reason, lawyers in their endeavor as professional men to contribute to the formation of public opinion often appear mainly to be engaged in direct short-range action. But it is a fair question whether their long-range influence, as exerted by an Elihu Root or an Oliver Wendell Holmes, is not the greater source of the power which this profession wields in clarifying public thinking on great questions of justice and human rights.

Other professional groups in the population, partly because they inherently are defined more loosely than these three, partly because the knowledge which they administer is more remote from the daily concerns of the people, cannot be traced so clearly in their influence on public thinking. Teachers, for instance, constitute a profession, but it is not so homogeneous as the medical profession, perhaps because it lacks the provisions for indoctrination of neophytes and the formalization of entry into mastership which are characteristic of such organically matured professions as medicine and the clergy. No one would fail to recognize the great influence for good which teachers exert altogether apart from their work of instructing the youth in a particular discipline, yet to trace the operation of that influence is baffling, in large measure because teachers as a professional group have not attained and really do not need to attain the comparatively close-ranked unity and self-regulation which, for example, the legal profession maintains.

ENGINEERING AND SCIENCE AS PROFESSIONS

These last comments are not made for the mere purpose of listing some more professional groups, but rather because they are significant in connection with the question of assumption of professional responsibilities by scientists and engineers. The general question implicit in our review of the dilemma of the professional man now is squarely before us. Natural scientists, physicists and chemists in particular, who in the past have been concerned primarily with the perpetuation and extension of knowledge and so have been more scholars than professional men, now are reaching the status of a profession. Engineers, who have had professional consciousness as a group for a considerable period and have expressed it through their continued efforts to develop an agreed code of ethics, encounter some difficulty over professional status because of their linkage with the economic and industrial structure. Yet I believe it has come to be recognized more widely that science and engineering are professions, even though not all scientists and engineers are professional men.

Why this development? There are many reasons, but for our present purpose we need cite only the most plain and direct of them. The esoteric equations of the mathematician and physicist of but a few years ago, as extended by further research, by applied science, and by technology and engineering, have become a matter on which the future and the fate of mankind depend—the reality of the release of atomic energy. Here, in the dispositions which the nations of the world decide to make in order to control or not to control a vast new force, the scientist perforce is brought out of his laboratory, for sound dispositions capable of assuring just and feasible utilization of this energy for the good of all men cannot hope for realization without his active help. Even if he wished, the physical scientist of today no more can cling to the isolated contemplation of knowledge than a romantic 14-year-old boy can go back to the days of Buffalo Bill. Rather, because of his special competence in a body of knowledge that has come to be a vital issue for the people as a whole, and that means not the people of the United States alone but the people

of all the world, the physical scientist is possessed of the authority and must accept the responsibility that mark the professional man as distinguished from the simple scholar.

In passing, let me observe that this last assertion is well substantiated by the fact that in the United States science as a professional calling and scientists as professional men are asking of the people the special consideration and the special position to which none but the professional rightly can lay claim. The legislation by means of which the people of the United States would establish a National Science Foundation insofar as it confers on science and scientists a special relationship to the rest of American life, justified by their disinterested contribution to the whole of American life, marks the coming of age of science as a profession. It is for those of us who are scientists and engineers to realize to the full that sharp and often onerous responsibilities accompany that special relationship.

As we do so, as we undertake to meet the responsibility of professional men to contribute as best they can to the formation of public policy, we encounter the same dilemma that other professional groups have met. It is assured that we shall exert a long-range indirect influence, and that we will pay sincere heed to it. Shall we superpose on it efforts at direct action, and if so, how far shall we go in this direction? There are degrees in direct action, and the crux of the problem is to make sure that the desire to help speed a social advance shall not carry us to a point in direct action which in the end will mean a net loss to society. How far in direct action can the scientist as a professional man go without unduly hazarding the disinterestedness which makes him a valuable member of the community? The classic divergence of views of government in the days of Alexander Hamilton and Thomas Jefferson is recalled in the implications of this question. As I see it, for all the value that direct action often has to recommend it, direct action, in a social and economic structure so complex and so intricately cross-connected as that in the United States today, can be very dangerous. I do not judge, I do not evaluate the issues in question, but I do point out that within recent months the United States has been brought to the very verge of impotence and frustration by the extreme direct action of a single small group in its population. Enthusiasts for direct action on any issue must remember this, and must balance possible ill effects against the supposed worth of speed—if direct action really does produce speed.

Science as a profession of course as yet has not reached its answer to the dilemma; it is in the process of doing so. Some scientists, some engineers, have turned to direct action involving at times the extreme techniques and tactics of the pressure group, conscious, one hopes, of the hazard they run of becoming ex-scientists or ex-engineers, as a result. It is too early yet to judge of the effectiveness of these groups. Some scientists, as witness those in the board of consultants who drew the notable state paper known as the Lilienthal report, have collaborated ably as professional men in laying bases for public policy, thus engaging in tempered direct action within the frame of government. Many, probably all, other scientists and engineers who are undecided as yet, are searching their minds as never before, in the sincere effort to determine what their duty is, and how best to perform it.

VALUE OF SELF-ANALYSIS

Thus we are brought back to the position of the sage who, in his insistence on definition and clear statement, was indeed the forerunner of the rigor and the discipline which scientists and engineers must strive for. We are brought back to Socrates, and to his declaration that an unexamined life is not worth living. Though in this swift-paced age the time is short, I welcome the fact that this is so, that the occasion for true analysis is on us, for I am sure that the end result cannot but be good. Thus far, I have spoken of science, and professions, and the professional man's dilemma, almost entirely in terms of the United States. Now let me go beyond that, for the full implications of the question, as concerns science, extend beyond national boundaries even though a sound solution of it will mean the greatest good at home.

In the self-scrutiny to which we are brought by the inescapable force of events, scientists and engineers possess, more immediately than any other professional group, two very great strengths. In the first place, their professional activities enrich them as a group with a greater frequency and a greater range of contact and collaboration with men of other nations than are enjoyed by other professions. In the second place, and more importantly, the very nature of the body of knowledge with which they deal knows neither time, nor place, nor nations, nor peoples. Astronomer or zoologist, Briton or Yugoslav, rock-ribbed Republican or Communist, in the face of the elusive and eternal objective truths with which he deals, the man of science is simply that—a scientist. As a profession, then, we have common ground with men of all kinds and conditions, common ground that in these days of the breathtakingly swift juxtaposition of races, creeds, cultures, and political philosophies is of inestimable value as a means toward understanding and mutual confidence. Whatever we do toward furthering meetings on that common ground, toward fortifying and confirming it as a starting point for other meetings by other men, is so much done toward the inculcation of collaboration and concord among the peoples of the earth.

Here is an ethical imperative such as no professional group before this time has had the privilege and the opportunity to meet. As here in the United States we examine the standards of honesty and objectivity which science requires but which our profession has not yet

brought together in a self-imposed and self-administered code of ethics, we shall accomplish two great ends. First, we shall clarify and confirm in our own minds what and why we are and how and why we best can share in the forming of the sound public opinion essential to strength and stability. Second, we shall chart the broad reaches of knowledge and determine the seamarks of sure intellectual and ethical principles which, because they are common to us as scientists, will be recognized by scientists everywhere as common to them also. Thus, in the full stature of a matured profession, men of science throughout the world can join in meeting the responsibility stemming from their ministry to the people and can do their full share in the formation of the enlightened world opinion which must be developed for peace among the nations to be assured.

The Sign of Reactive Power

AN AIEE COMMITTEE REPORT

By arbitrary definition inductive reactive power is considered negative. Ample justification seems to exist for changing the sign of reactive power, and the steps already taken in that direction are reflected here. Comments from the readers should be addressed to the secretary, AIEE Standards committee, 33 West 39th Street, New York 18, N. Y.

IN RECENT YEARS the concept of reactive power and its flow in electric circuits has become an extremely useful concept in power system analysis and operation. To provide definiteness in technical discussions, in analytical and network calculator investigations, and in recording system power readings for dispatching and similar operating purposes, it is highly desirable that the sign associated with the reactive power under definite circuit conditions should be standardized and that practice generally should agree with the standard. As explained here, there are two possible conventions for the choice of sign for reactive power, both of which have about equal technical validity. One of these has been adopted as standard by the American Standards Association and incorporated in the "American Standard Definitions of Electrical Terms," ASA C-42, in definition 05.21.050. However, as the concept of reactive power became more widely used, its users have become more thoroughly convinced that the opposite sign was preferable, for reasons that are practical rather than technical. At present, therefore, practice is predominantly the opposite of the standard.

The question is not one of positive direction but of positive concept. To analyze a sinusoidal a-c circuit precisely at any pair of terminals or points of entry it is necessary to assign, definitely or tacitly, an assumed positive direction of current to the circuit and an assumed polarity to the terminals. Then, under either concept, the current is positive when its instantaneous direction is the assumed positive direction, and the voltage is positive when the assumed positive-polarity terminal is instantaneously at a higher potential than the other. With no other assumptions, the instantaneous power is positive when the instantaneous current and voltage are both positive or both negative, and the average real power is positive if the phase angle between the corresponding current vector and voltage vector is less than 90 degrees. However, the assumptions made are insufficient to determine whether the reactive power at the same points of measurement under the same conditions is positive when the voltage vector leads the current vector (by less than 180 degrees) or when the current vector leads the voltage vector. An additional concept or assumption is necessary and unless all users make the same assumption confusion results.

Recognizing that this confusion is undesirable, the Standards committee of the AIEE, acting on a recommendation of the power transmission and distribution committee, in May 1944 appointed a subcommittee to investigate this matter and make suitable recommendations. In June 1945 this subcommittee, by two-thirds vote, recommended that the American Standard Definition 05.21.050 be changed to agree

This report was prepared by a subcommittee of the AIEE Standards committee, consisting of **R. C. Bergvall** (M '41, *chairman*), assistant to the vice-president, engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa.; **W. A. Lewis** (F '45, *acting chairman*), consultant in electrical engineering, Armour Research Foundation, Chicago, Ill.; **W. R. Brownlee** (M '38), investigations division, Commonwealth and Southern Corporation, Jackson, Mich.; **S. B. Crary** (M '38), central station engineering division, General Electric Company, Schenectady, N. Y.; **H. L. Curtis** (F '26), physicist, National Bureau of Standards, Washington, D. C.; **A. E. Knowlton** (F '30), associate editor, *Electrical World*, McGraw-Hill Publishing Company, New York, N. Y.; **W. C. Sealey** (M '38), engineer in charge, transformer division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; **H. K. Sels** (F '45), transmission and substation engineer, Public Service Electric and Gas Company, Newark, N. J.; **H. M. Trueblood** (F '40), protection development engineer, transmission engineering department, Bell Telephone Laboratories, New York, N. Y.; **S. H. Wright** (M '34), electrical engineer, Ebasco Services, Inc., New York, N. Y.

with existing widespread practice, and that the standard sign for reactive power be reversed. The Standards committee accepted the report and referred it for further action to the American Standards Association. The appropriate ASA committee, C-42, on standard definitions of electrical terms at present is not organized to handle such matters. While this ASA committee is being reorganized, the present article is being published, to solicit general discussion, so that, if possible, the necessity for further delay may be obviated when the reorganization of ASA committee C-42 is completed.

THE CONCEPT OF REACTIVE POWER

Series Circuit. Figure 1 shows a series inductive circuit of resistance R and inductive reactance X, carrying a sinusoidal current. On a conventional impedance diagram, R is drawn horizontal and X vertically upward, as shown in Figure 2*a*. In complex-quantity notation, the impedance $\boldsymbol{Z}$ is

$$\boldsymbol{Z} = R + jX \tag{1}$$

The corresponding voltage and current vectors, $\boldsymbol{V}$ and $\boldsymbol{I}$, are shown in Figure 2*b*, with the voltage leading by the angle ϕ. The average real power, P, absorbed by this circuit is given by the familiar relation

$$P = RI^2 \tag{2}$$

where I is the magnitude of the current vector $\boldsymbol{I}$. This quantity is, of course, the average instantaneous power, where the instantaneous power is itself a double-frequency quantity.

By analogous reasoning, the reactive power may be *defined* as

$$Q = XI^2 \tag{3}$$

and it is measured in vars, or multiple units, as kilovars, megavars, and so forth.

For many purposes it is convenient to plot both the real power, P, and the reactive power, Q, on the same diagram. This may be done by plotting real power horizontally and positive reactive power vertically upward, as in Figure 3, in which the real power is represented by P and the reactive power by jQ.

For convenience, the vector sum of these two quantities, when the current and voltage are sinusoidal, is defined as the vector power, $\boldsymbol{S}$, so that

$$\begin{aligned} \boldsymbol{S} &= P + jQ \\ &= RI^2 + jXI^2 \\ &= (R + jX)I^2 \\ &= \boldsymbol{Z}I^2 \end{aligned} \tag{4}$$

In accordance with this concept, vector power is the product of the impedance, treated as a complex quantity, and the square of (the magnitude of) the current.

It is well known that the real power, P, may be expressed also as

$$\begin{aligned} P &= VI\cos\phi \\ &= VI\cos(\alpha - \beta) \end{aligned} \tag{5}$$

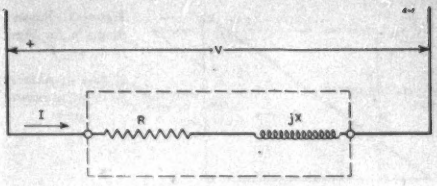

Figure 1. Series circuit

and the reactive power as

$$\begin{aligned} Q &= VI\sin\phi \\ &= VI\sin(\alpha - \beta) \end{aligned} \tag{6}$$

In order that Q in equation 6 may agree with Q in equation 3, it is necessary that ϕ in Figure 2*b* be taken as positive. That is, the angle ϕ must be defined as the (positive) angle by which the voltage $\boldsymbol{V}$ leads the current $\boldsymbol{I}$, or

$$\phi = \alpha - \beta \tag{7}$$

In terms of equations 5 and 6, the vector power becomes

$$\begin{aligned} \boldsymbol{S} &= P + jQ = VI(\cos\phi + j\sin\phi) \\ &= VI[\cos(\alpha - \beta) + j\sin(\alpha - \beta)] \\ &= VIe^{j\phi} = Ve^{j\alpha}Ie^{-j\beta} \end{aligned} \tag{8}$$

The voltage and current vectors are given by

$$\begin{aligned} \boldsymbol{V} &= Ve^{j\alpha} \\ \boldsymbol{I} &= Ie^{j\beta} \end{aligned} \tag{9}$$

The conjugate of the current vector is, by definition, a vector having the same magnitude but the opposite phase angle. Therefore, the conjugate of the current vector is

$$\text{conj } \boldsymbol{I} = Ie^{-j\beta} \tag{10}$$

Substituting $\boldsymbol{V}$ and conjugate $\boldsymbol{I}$ in equation 8 shows that the vector power may also be expressed as

$$\boldsymbol{S} = P + jQ = \boldsymbol{V}\,\text{conj}\,\boldsymbol{I} \tag{11}$$

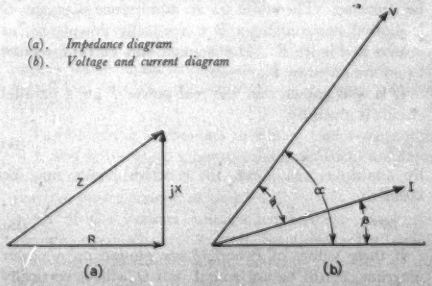

Figure 2. Impedance and voltage–current relations for Figure 1

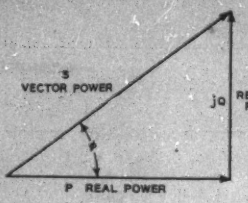

Figure 3. Power diagram for Figure 1

Q taken as positive for inductive reactive power

or, stated in words, the vector power is equal to the product of the voltage vector and the conjugate of the current vector. The real part of the vector power is the real power and the imaginary part is the reactive power.

Parallel Circuit. If the resistance and reactance of Figure 1 were enclosed in a box so that only the terminals were accessible, the circuit could be represented equally well by a resistance and reactance of suitable values connected in parallel, as shown in Figure 4. By measurements at the normal frequency, made at the terminals only, it is not possible to determine whether the circuit is a series or parallel circuit. For equivalence, the parallel circuit must have an admittance Y given by

$$\begin{aligned} Y &= G+jB \\ &= \frac{1}{Z} \\ &= \frac{1}{R+jX} \\ &= \frac{R-jX}{R^2+X^2} \end{aligned} \tag{12}$$

from which

$$\begin{aligned} G &= \frac{R}{R^2+X^2} \\ B &= -\frac{X}{R^2+X^2} \end{aligned} \tag{13}$$

That is, if the reactance, X, is positive, as for an inductive circuit, the corresponding susceptance, B, must be negative. Therefore, on an admittance diagram, G is plotted horizontally and B vertically downward, as shown in Figure 5. The voltage and current vectors again are given by Figure 2*b*.

It is well known that the real power P for a parallel circuit is given by

$$P = GV^2 \tag{14}$$

By analogous reasoning, the reactive power may be *defined* as

$$Q = BV^2 \tag{15}$$

If these values of P and Q are plotted on a power diagram, P will be horizontal, but Q will be vertically *downward*, as shown in Figure 6, because its value is negative when B is negative in equation 15.

That is, if reactive power is *defined* on the basis of a series circuit, by analogy with the impedance, using equation 3, its numerical value will have the opposite sign to what it would be if reactive power were *defined*, by analogy with the admittance, by equation 15. The real power, it may be noticed, is the same in either case.

The vector power, taken as the vector sum of the real and reactive power quantities in Figure 6, will be

$$\begin{aligned} S &= P+jQ \\ &= GV^2+jBV^2 \\ &= (G+jB)V^2 \\ &= YV^2 \end{aligned} \tag{16}$$

With the definition based upon a parallel circuit, vector power is the product of the admittance, treated as a complex quantity, and the square of (the magnitude of) the voltage.

In terms of V and I, P and Q now become

$$\begin{aligned} P &= VI\cos\phi = VI\cos(\beta-\alpha) \\ Q &= VI\sin\phi = VI\sin(\beta-\alpha) \end{aligned} \tag{17}$$

In order that Q in equation 17 may agree with Q in equation 15 it is now necessary that ϕ in Figure 2*b* be taken as negative. That is, the angle ϕ must be defined as the angle by which the current I leads the voltage V, and is negative when the voltage leads. In other words,

$$\phi = \beta-\alpha \tag{18}$$

which is the opposite of equation 7.

In terms of equation 17, the vector power becomes

$$\begin{aligned} S &= P+jQ = VI[\cos(\beta-\alpha)+j\sin(\beta-\alpha)] \\ &= Ve^{-j\alpha}Ie^{j\beta} = \text{conj } VI \end{aligned} \tag{19}$$

where

$$\text{conj } V = Ve^{-j\alpha} \tag{20}$$

is the conjugate of the voltage vector. With the definition of reactive power based on a parallel circuit, the vector power is equal to the product of the conjugate of the voltage vector and the current vector. This is the opposite, that is, the conjugate of equation 11.

ARBITRARY CHOICE OF SIGN OF REACTIVE POWER

The two preceding sections have demonstrated that there are two technically valid choices for the definition

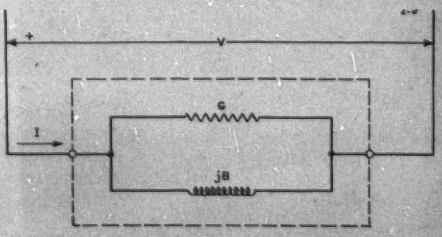

Figure 4. Parallel circuit equivalent of Figure 1

of reactive power, one based on a series circuit and an analogy with impedance and the other based on a parallel circuit and an analogy with admittance. If the first choice is selected, the reactive power absorbed by an inductive load is *positive;* if the second choice is selected, the reactive power absorbed by an inductive load is *negative*. The first choice is now recommended by the subcommittee, because of practical considerations, and corresponds to the series-circuit analogy. The second choice is the existing standard. From the standpoint of the preceding analysis, the choice is arbitrary, as there is no means of stating positively that the series circuit is more fundamental than the parallel circuit, or vice versa.

Either definition can be used consistently for either series or parallel circuits, but the analogy between the vector power diagram and the impedance and admittance diagrams cannot be maintained for both cases. If the first convention is chosen, the vector power diagram is similar to the impedance diagram but is similar to the *image* of the admittance diagram. The reactive power, Q, will have the opposite sign to B and will be plotted in the opposite direction. If the second convention is chosen, the vector power diagram will be similar to the admittance diagram, but will be similar to the *image* of the impedance diagram.

The present ASA Standard published in 1942 followed the results of a ballot taken about 13 years ago to determine whether the vector representing inductive reactive power should be drawn upward or downward. At that time there was little preponderance in favor of either standard, and the decision was based largely upon the fact that power system loads consist of many individual loads connected in parallel. For power purposes, a choice based on the parallel circuit then seemed the more rational. The present recommendation of the subcommittee is that inductive reactive power be defined as a positive quantity, corresponding to the series-circuit analogy, for the practical reasons discussed in the next section.

PRACTICAL CONSIDERATIONS IN SELECTING THE SIGN OF REACTIVE POWER

In spite of the ASA definition referred to, the preponderant use of the concept of reactive power has favored the first concept in which the reactive power absorbed by an inductive load is positive. In the following discussion, therefore, the advantages of the first concept, from a practical viewpoint, will be stated.

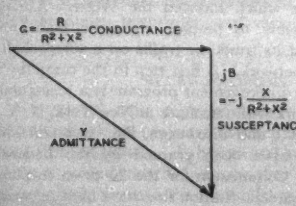

Figure 5. Admittance diagram for the circuits of Figures 1 and 4

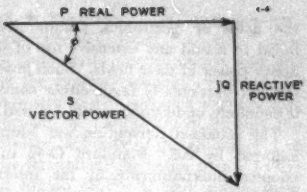

Figure 6. Power diagram for Figure 4

Q taken as negative for inductive reactive power

1. Most loads are inductive and absorb positive real power (kilowatts) and inductive reactive power (kilovars) *from* the system.

With the proposed definition, the reactive power of the most common loads will be positive, and both kilowatt-hour and kilovar-hour meters will normally rotate in the positive direction.

2. Rate structures commonly are based on charging for the integrated use of real and inductive reactive power, both considered as positive quantities.

With inductive reactive power positive, the customer is charged for the integral of the reactive power or the kilovar-hours which he consumes. With the opposite convention he is charged for the kilovar-hours which he supplies to the power system, and the more he supplies, the more he is charged.

3. Inductive reactive power causes a voltage drop in the direction of its "flow" through an inductive circuit, just as real power causes a voltage drop in its direction of flow through a resistive circuit.

With inductive reactive power as positive, positive real power flow and positive reactive power flow both produce voltage drops in the direction of flow in normal circuits. With the opposite convention, positive reactive power flow produces a voltage rise in the direction of flow.

4. Both real power and inductive reactive power are "lost" in the process of transmission.

With inductive reactive power as positive, both real and reactive power "losses" are positive in normal circuits.

5. Increasing the prime mover input to a synchronous generator increases its real power output. Increasing the field excitation increases the inductive reactive power output.

With inductive reactive power as positive, a positive increase in both real and reactive power output will accompany an increase in the corresponding input quantity.

6. Generator wattmeter and varmeter indications will be better co-ordinated.

With inductive reactive power as positive, varmeters should be designed to read upscale (to the right) with increasing inductive reactive power, instead of downscale (to the left). Then with normal load increases, both wattmeters and varmeters will read farther to the right.

To obtain the advantages described under reasons 1, 3, 4, and 5, the great majority of a-c network calculator studies of power systems have been made with inductive reactive power treated as positive.

All of the reasons enumerated strongly favor the recommended change in the Standard. No corresponding reasons were found favoring retention of the present Standard. Although all of these reasons are based upon the normal operation of power systems, and do not include specifically other applicatons, a survey of

the fields of electronics, communication, and radio failed to reveal any extensive use of the concept of reactive power in these fields. Such practice as was found did not particularly favor either convention, as either, if definitely understood, could be used equally well.

The standard convention was adopted in 1935, was followed by ASA Standard C-42 in 1942, and was adopted internationally by the International Electrotechnical Commission. Some opposition to the proposed change has been voiced by two of ten committee members because of the international sanction given the present standard. However, the survey by the subcommittee showed that the standard was not being widely followed, and that there was little probability that the preponderant users would give up the definite advantages of their present practice for the nebulous advantages of using an unwieldy standard. No workable compromise which would allow the standard to remain unaltered and would at the same time meet the objections to it could be found. Therefore the subcommittee, with the concurrence of the AIEE Standards committee, recommends that the American Standards Association, acting for the United States, adopt the change and recommend that other nations do likewise. In no other way, in the opinion of the subcommittee, can the standard, as it is intended to do, express the meaning of the term "reactive power" as it generally is employed in electrical engineering.

Discussion and comment on the recommendation are solicited. Letters should be addressed to the secretary, AIEE Standards committee, 33 West 39th Street, New York 18, N. Y.

Radio Relays for Telegraphy

F. B. BRAMHALL
FELLOW AIEE

With the opening of the superhigh frequency spectrum, the American telegraph industry now finds it economically possible to utilize radio relaying and still attain the necessary high degree of circuit stability and continuity. However, radio power is not yet practical for smaller systems but should be reserved for routes with relatively heavy traffic loads such as the proposed New York–Washington–Pittsburgh network.

THE DOMESTIC telegraph industry of the United States has come to expect a degree of circuit stability and continuity which, until now, has been economically quite impossible for radio to attain. The opening of the superhigh frequency spectrum under the impetus of military necessity for radio locators has changed this picture however. The highly directional antennas of practical size available for frequencies from 3,000 megacycles up, and the complete absence of natural and man-made noises in this region, make it possible today to obtain with a fraction of a watt of radio power the results formerly achieved with 100 kw.

The ability to beam the transmitted radio energy in a very narrow cone, and the geometric line-of-sight behavior of the propagation, permit the establishment of a comprehensive network with an absolute minimum number of radio frequency channels. In fact, as many as eight separate circuits can be operated into a heavy traffic center on a single frequency. Noninterfering reception can be accomplished on the same frequency in every 45 degrees of the compass. Likewise, a second frequency may be used for transmission in the opposite direction, if the beam directions are separated by 45 degrees. It is perhaps ironical, but certainly fortunate, that the same frequency register which admits of highly directional beams, at the moment seems to be the one region of the spectrum which will not become overcrowded in the immediate future. These considerations are among those which induced the Western Union Telegraph Company to prepare elaborate plans for handling much of its trunkline traffic on a comprehensive radio relay network. A first step in the company's extensive postwar improvement program is a triangular radio relay network with terminals at New York, N. Y., Washington, D. C., and Pittsburgh, Pa. Construction permits already have been granted by the Federal Communications Commission for the 20 or so stations required in this system. Station sites have been selected

Essential substance of a paper presented at the AIEE South West District meeting, San Antonio, Tex., April 16–18, 1946.

F. B. Bramhall is transmission research engineer, The Western Union Telegraph Company, New York, N. Y.

Figure 1. Design for suburban relay terminal tower for large city

and purchased or leased, building construction is already under way, and equipment commitments have been made. The derived facilities will be used for all types of record communication circuits, including multiplex, facsimile, teleprinter, and various other business aids.

RELAY STATIONS

Unattended radio relay stations, spaced from 20 to 50 miles apart, are projected between many of the major heavy traffic centers. Experimental work done during the past several months indicates that a geometric line-of-sight path between the transmitting radiator and the receiving collector is mandatory. In open country, therefore, the accessibility of elevated relay station sites, the availability of commercial electric power, and like factors, determine the repeater spacing. Propagation studies, though nowhere nearly adequate scientifically, already have indicated the desirability of keeping the transmission path clear, not only of the ground, but of trees and buildings throughout the entire span. In the eastern mountain section of the United States, these considerations led to open country spacings which average about 40 miles per hop. In this type of country, of course, advantage is taken of relatively high ground but, generally speaking, the highest mountain tops are avoided. Near certain large centers of population, short hops sometimes result from the fact that such cities frequently are located in relative depressions of topography.

The experience on which the present conclusions are based was gained mainly in the region of 4,000 megacycles. In this region, fog, rain, snow, and other weather phenomena most commonly met cause no serious change in signal attenuation. Throughout all seasons of the year, the phenomenon called "slow fading" is encountered, presumably resulting from a bending of the beam caused by either temperature or humidity gradients from the earth's surface upward. The magnitude of this fading over a 30-mile span can be said to be in the neighborhood of 30 decibels. At certain seasons of the year, a phenomenon called "rapid fading" causes the received signal to fluctuate wildly in a manner which definitely suggests the multipath cancellation well known in longer wave radio transmission, and attributed to ionized layers in the upper atmosphere. It seems quite obvious that the reflections which cause multipath fading in the superhigh frequency region do not come from higher reaches of the atmosphere. A sufficient reason for this conclusion is the extreme directivity of the receiving antenna, its effective beam being six degrees in total width. The most logical present postulate is that at times of perfect atmospheric quiet, extremely flat and continuous stratification of either temperature or humidity, probably both, are responsible. The rare conditions under which multipath cancellation of this type occurs seem to be most prevalent in the early morning hours of the early summer months. Experience to date indicates that little difficulty is met in overcoming the slow fading phenomenon by conventional methods, and that the rapid fading phenomenon can be overcome, as in long wave transmission, by diversity reception.

RADIO RELAYING VERSUS WIRE LINES

The economics of radio relaying in competition with wire lines indicate that the former medium is justified only for relatively heavy traffic loads. For a single telegraph printer circuit, radio is quite out of the question. Even for several score of printer circuits, it is

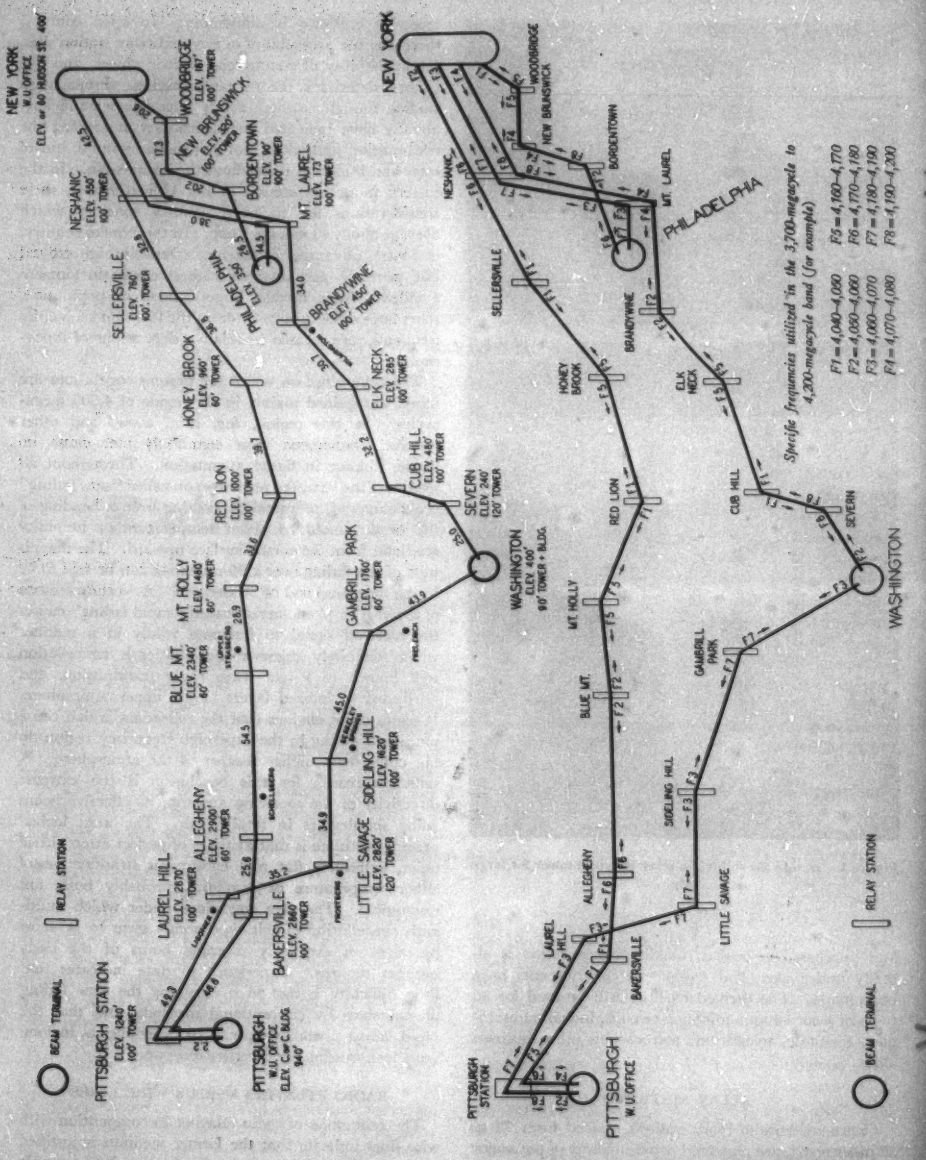

Figure 2. Location and elevation of towers in radio relay system between New York, Washington, and Pittsburgh

Figure 3. Chart of New York–Washington–Pittsburgh radio relay system showing typical transmitter frequency assignments

certainly of very doubtful economy. For several hundred, the studies indicate that the kind of equipment and the grade of maintenance, necessitated by the high continuity standards to be met, can be justified. Considerations of this nature have led to the adoption of a useful "audio" channel width of 150 kc. This amount of "audio" spectrum is capable of division into 1,080 teleprinter operating circuits.

The term "audio" is used in this article, not in any literal sense, but only to indicate the analogy between the present development and the most familiar radio telephone practice. One of the outstanding technical features of the present development is the ability of the radio modulation system to handle such a great number of independent signaling frequencies without the production of a prohibitive amount of interchannel interference. The final superhigh frequency radio carrier is, of course, frequency modulated. The maximum frequency swing, conforming generally to accepted practices, is in the neighborhood of ±2.0 megacycles. The available sources of superhigh frequencies lend themselves most readily to frequency modulation, and limiting amplifiers are extremely effective and simple devices for the mitigation of the effects of fading. These and several other factors, centered around the extreme requirements for "audio" band linearity, led naturally to the choice of frequency modulation. Present techniques for the measurement, generation, and control of frequency in the superhigh frequencies region leave something to be desired in the way of radio spectrum economy. The system employed requires that the nominal radio carriers be separated by not less than ten megacycles in the 4,000-megacycle region. Proportionally greater channel separation will be needed at higher frequencies.

As yet, too little data are at hand to permit even an intelligent guess as to whether the 4,000-megacycle region is the proper location for a telegraph radio relaying network. Perhaps some of the fading phenomena observed will exhibit different characteristics in another region. It is known, of course, that as the frequency is increased on up toward 30,000 megacycles, moisture particles in the atmosphere can increase the path attenuation seriously.

THE CARRIER SYSTEM

The carrier system developed to permit so great a number of separate telegraph communication circuits to be stacked in a 150-kc band is unique even to the wire communication art. It is, of course, a single sideband system, resulting finally, at the "audio" input to the radio equipment, in one independent carrier frequency for each derived telegraph channel. Telegraph channels are grouped by the single sideband modulation equipment, each group containing eight telegraph carriers spaced 150 cycles apart, and capable of operation by frequency modulation at 66 bauds (33 cycles per second). The translating system, by means of which eight separate voice frequencies ranging from 525 cycles to 1,575 cycles are stacked one above the other up to 150 kc, differs from the conventional translating systems used in carrier telephony in that individual voice band filters are not required. Hence the method of translation avoids the wasteful guard bands necessary in the conventional technique and permits an economy of spectrum utilization previously obtainable only through the use of relatively expensive crystal filters.

Frequency modulation of the primary "audio" telegraph carrier is a technique adopted by the Western Union company several years back, and is in very extensive use in the company's wire communication network. Using a deviation ratio of one, it affords a degree of freedom from the distortion caused by level changes and extraneous disturbances not possible in amplitude-modulated telegraphy. The contemplation of frequency modulation on a telegraph channel, which uses discriminators sensitive to a frequency drift of even two cycles, brings a realization of the frequency accuracy

Figure 4. Relay repeater tower of New York–Philadelphia experimental system

required in the oscillators of the 150-kc translating equipment. This problem is solved through the use of an accurate temperature-controlled reference crystal.

RADIO TERMINALS

Serving only the heavily loaded trunk routes, radio system terminals generally are located in business centers of large cities where adequate elevation is secured for antennas on tall office buildings. In installations of this type now under construction, the antennas are mounted on a suitable frame on the roof or inside a penthouse. Radio equipment, back to the "audio" band circuit, is located either in the penthouse or in nearby space on the floor directly underneath. Carrier translating equipment for the first breakdown to 3-kc voice bands is installed in equipment rooms already established for wire carrier operation.

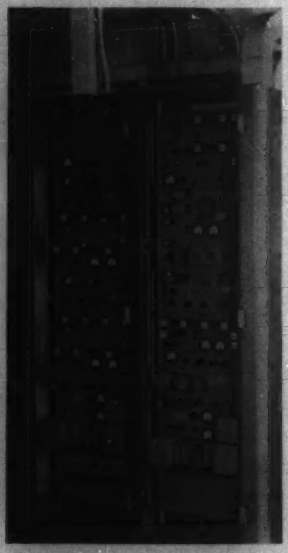

Figure 5. Two-way radio equipment at terminal stations

Another form of radio terminal installation is that located in the restricted suburban outskirts of Washington, D. C., where a rather elaborate monolith type of structure houses the antennas on top. The radio equipment is on an upper floor, the carrier translating equipment, reserve power plants, and facilities for a 24-hour staff of attendants are in the base of the tower and in an adjacent building. In this type of installation, the 3-kc voice bands are carried to the central telegraph office in the heart of the city on underground cable pairs. Various other terminal conditions are encountered, one in which adequate space for the voice band translating equipment is not obtainable at the radio site. In this case, the 150-kc band is carried to the central telegraph office with a mile or more of coaxial cable. It will be understood that terminals of the type discussed generally do not appear as single units, inasmuch as there are alternate routes and other connecting radio circuits radiating from one central location.

At the repeater stations, an open steel tower of considerable rigidity mounts the antennas in a small penthouse. At these stations, a final radio stage on the outgoing side and the initial amplifier on the incoming side are mounted within the penthouse close to the antennas. All other equipment is housed in a rugged building at the base of the tower. This building generally is supplied with commercial power; it has overnight accommodations for a visiting attendant, and a reserve power plant in addition to the radio equipment itself. To facilitate maintenance, automatic switching functions and alarms will be installed at all unattended stations. To one or both terminals of a chain of relay stations, indications of radio equipment and power supply conditions will be conveyed over the radio carrier itself, quite independent of whether the system is carrying live traffic loads or not. Furthermore without disturbance to an operating system, a visiting maintenance man may converse by telephone with other stations in the chains and with the terminals. Plans call for strategically located maintenance men to cover a segment of the chain by automobile, caring for three or more stations. With the automobile will go certain less critical spare equipment components while other spare parts and test gear will be kept at each station. For the most part, equipment servicing repairs will be made at the attendant's headquarters.

RESULTS

By materially reducing circuit interruptions resulting from storms, falling trees, and electrical disturbances, the radio relay system is expected to improve the quality, dependability, and speed of telegraph service provided to the public. From an initial trial installation with a 3-link system from New York to Philadelphia a little more than a year ago, much progress in the development of this service has been made. Credit for adapting what were essentially radar techniques to a vital communication need is due the engineers of the Victor division of the Radio Corporation of America, while responsibility for the application of the medium to the exacting requirements of the industry was assumed by engineers of the Western Union company. These engineers have developed the high capacity carrier system, which makes the new medium an economic practicability. Activities are already well under way for extension of a network well beyond the New York–Washington–Pittsburgh triangle previously mentioned.

Human Progress

C. T. WELLER
MEMBER AIEE

THE halfway mark of the 20th century is still ahead, yet so far there have been two major wars and a third is entirely possible. The human traits responsible for the wars and for the ensuing turmoil are evil enough, but some of the behavior, such as the killing and torturing of the helpless, is on the animal level. Although such traits and behavior were characteristic of large groups in enemy countries they were not restricted to them, so it might be concluded that human progress is stalled if it is not actually in reverse. Before accepting such a pessimistic view it might be well to look back into the past.

This earth, which seems so large to us, is only a tiny part of a universe so immense that its dimensions, if known, would be almost beyond comprehension. Yet the earth may be the only place in all that vast expanse where life such as ours exists. It is estimated that the age of the earth is nearly two billion years and that man has occupied it for at least 500,000 years. Both of these estimates are comparatively new. Many can recall when it was believed that man's sojourn on the earth did not exceed 10,000 years, and even that a definite date could be assigned to his advent.

It required the discovery of radium and the rate of decay of radioactivity in various elements before a reasonable estimate could be made of the age of the earth. It required the discovery of the remains of numerous ancient men and careful appraisal of the formations in which they were found before a reasonable estimate could be made regarding man's occupancy. Some of the most important discoveries have been made in the last half century, which is very recent when compared with the age of the earth.

The largest group of ancient men was discovered, where one might expect it to be in a northern Asiatic climate; in a cave meeting one of the basic human needs—shelter. The cave is located at Chow Kow Tien (or Choukoutien), near Peking, China, and the human remains are known as Peking man. Some of the artifacts were carried off by the Japanese invaders but they were unable to find the carefully hidden bones. Ultimately, all Chow Kow Tien items will be displayed in China; some reproductions now are on display in the United States. It is with reference to such ancient individuals as Peking man that human progress must be evaluated.

Essential substance of an address broadcast May 8, 1946, from stations WGY and WGFM, Schenectady, N. Y., during the General Electric Science Forum program.

C. T. Weller is an electrical engineer, general engineering and consulting laboratory, General Electric Company, Schenectady, N. Y.

Let us visit Peking man in his limestone cave. Perhaps we can slip in while he is away hunting. We find a fire burning and some crude stone tools and bone implements nearby, together with hides, meat, and bones of species of animals now extinct. Otherwise, the cave looks quite bare. His ceaseless struggle for survival apparently has made our host suspicious but we can catch a glimpse of him as he hesitates to approach. He is repulsive to us with his wide, low head, his high brow ridges, and his powerful jaw. He seems to be dominated by fear and unable to speak.

How do we know so much about Peking man? The tools and animal bones were found near his remains, some charred by fire. The skull is most revealing; we can look into that cradle of personality, the brain case. A cast of the brain indicates that the areas associated with intelligent speech were not well developed. Compared with that of modern man the brain is about three-quarter size.

Now suppose that Peking man were to return our visit. He would find our shelters very comfortable because we have learned enough about air conditioning to keep them warm in winter and cool in summer. He would note the windows that keep out cold and heat but admit light. At night, he would appreciate ample artificial light available merely by flipping a switch. It would take considerable time for him to become accustomed to our furniture and clothes but not to our abundant food made possible by canning, refrigeration, and transportation; fruits and vegetables fresh the year around or canned, grains, and meats baked or roasted a predetermined time at a predetermined heat in a modern range. He would understand the uses of some of our household tools but not the lack of weapons. The radio and television set would amaze him. Outdoors, he would see the basic industries of agriculture and lumbering, animal husbandry and fishing, mining and quarrying, and then a bewildering variety of manufacturing, all utilizing power in some form. He could not help but notice that we spew our smoke and soot freely into the air just as he did, nor would he approve our urban habit of sluicing wastes into the nearest stream. On the other hand, he would admire our modes of transportation, especially in air, but also on and under land and sea.

Our visitor probably would be impressed most of all with our assurance, our confidence. He could not know that it resulted from what is perhaps the greatest achievement of science: the assembling of irrefutable evidence that this is a universe of law and order. It operates

with a precision that modern man has the utmost difficulty in matching. If carefully set up, the thousandth, the 100 thousandth, and the millionth experiment give exactly the same result as the first. To the ancient Greeks we owe much of the credit for initiating the change-over from the earlier belief that the universe was subject to the unpredictable whims of super beings, mostly of evil intent. Such beliefs provide fertile soil for the growth of fear and superstition.

Modern beliefs also go beyond science. Many believe that there is purpose in the universe and that life is one manifestation of that purpose. In the maintenance and extension of life the success achieved has been extraordinary. At the apex of an almost infinite number and variety of living things are more than two billion human beings. This mass of humanity is dominated by a single objective: satisfaction. Satisfaction is expressed in ways that have not changed since remote times: gratification of the senses, physical and mental achievement, the quests for certainty, for security, and for power. Under proper control these lead to the highest type of civilization; out of control they lead to individual and national disintegration and to war.

War is not necessarily a bar to progress. War brings out the best of human traits as well as the worst. It stifles basic research but it stimulates applied research and development. War tends to focus attention on human behavior and its causation. Remedial measures are frequently possible and are an important function of international co-operation. A powerful incentive is supplied by the suffering, loss of life, and destruction of wealth in war. Compared with the 19th century, the present extent of co-operation by the United States with foreign nations may come to be considered a milestone of progress. In the domestic field, progress in reducing losses of life and wealth by accident and by fire and in cleaning up the air and streams must be recognized.

This brief survey indicates outstanding progress since Peking man, probably painfully slow at first, and very uneven, but cumulative. If modern man will profit by the lessons of the past, he can face the future with optimism!

The Automatic Sequence Controlled Calculator—III

HOWARD H. AIKEN GRACE M. HOPPER

WHEN A RELATIVELY LARGE number of values, such as constants or random values of a variable, are to be used by the calculator, and further, when these values are to be used in a prescribed order, they may be supplied to the machine via one of the interpolator mechanisms and a perforated paper tape. Such a tape is known as a "value tape" to distinguish it from a functional tape. Mathematically, the operation of reading from a value tape is the equivalent of zero order interpolation. In order to increase the flexibility of the interpolators when used in this manner, three sequence codes have been assigned to each interpolator mechanism. These require that the tape be stepped forward, stepped back, and that the sensing pins read from the tape.

THE CARD FEEDS

Other means of supplying data to the calculator are the two card feeds shown in Figure 1. These employ standard tabulating machine cards and have three advantages over the value tape. First, inasmuch as the tabulating machines are standardized highly, the cards permit the interchange of data from one computation laboratory to another. Second, the devices required in the manual preparation of the cards have been developed to a high degree of perfection. Third, the calculator itself is equipped with a card punching mechanism.

The disadvantage of punched cards as compared with a value tape lies in the fact that the card feeds must accept the cards in the order in which the deck is stacked. No provision is made for retrieving a card once it has passed through the feed. Hence, a second use of the value punched in a card requires the intervention of the machine attendant. When punched cards and value tapes are being used, the coding must be arranged to synchronize their reading units with the main control tape. This implies that suitable operating instructions must be prepared to insure that cards and value tapes are inserted in the calculator properly.

A control is provided on each card feed to stop the

calculator when the cards are exhausted or jammed. The quantities in the cards are read into the bus through plugging and therefore may be shifted to conform with the operating decimal position. This is not true, however, of value tapes.

Occasionally a problem is so voluminous as to tax the facilities of the calculator. In such cases, the main control tapes are designed so that the computation may proceed part way, the intermediate results may be punched into cards, and the cards later fed into the calculator for further computation under the direction of a second main control tape.

With this issue is concluded a 3-part article describing the automatic sequence controlled calculator developed to carry out any selected sequence of the five fundamental operations of arithmetic. Part III discusses the preparation and planning of the sequence control tapes.

The card feeds and interpolator mechanisms, together with the switches described previously, represent the means by which numbers may be introduced into the calculator as a basis for computation. For recording computed results, two methods are available: the card punch mentioned in the previous paragraph and two automatic typewriters, Figure 1.

THE "PRINT" AND "PUNCH" COUNTERS

The printing and punching of numbers are accomplished with the aid of registers known as the "print" and "punch" counters together with special circuits designed to control the recording devices. The print and punch counters (Figure 2) are equipped with in- and out-relays and complete carry circuits so that they function as standard storage counters in addition to performing their special purposes.

The controls of the typewriters are very flexible with respect to the number of digits printed, their spacing, columnar position, and line spacing. The computed results may be reproduced photographically directly from the typewritten sheets. This avoids the possibility of error due to copying, inherent in most computational procedures. In order to avoid the loss of computed results, the card punch is equipped with a stop control which prevents read-in to the punch counter, stops the calculator, and lights a red signal light in the event that a blank card is not in the proper punching position at the time the sequence control tape dictates the punching operation.

Not all problems imposed on the calculator require the use of punched cards. Hence, a manual keyboard connected with the punch may be used for the preparation of cards while the calculator is in operation. This punch, however, does not produce any of the tapes used by the machine. The Jacquard weavers laced their cards together to provide the tapes they required for the control of their looms. The calculator, on the other hand, uses smooth tapes prepared by means of a specially designed manual punch shown in Figure 3.

Two keyboards are used interchangeably to control this punch. The first of these is used in the preparation of functional and value tapes. It has 24 columnar positions and perforates the tape in such a way as to represent any one of the ten digits in each column of a 23-figure number together with the algebraic sign. A 4-line code is used as shown in Figure 4. This figure must be read from the bottom to the top, representing the forward direction in which the tape passes through the reading mechanisms of the interpolator units.

In general, a value tape consists of a tabulation of constants punched into the tape in a given order. A functional tape, on the other hand, contains a group of entries associated with each argument. The first entry in each group is the argument itself. This is followed by the interpolational coefficients, c_n, c_{n-1}, . . . , c_1, c_0 in this order.

The main control tapes are punched by the second keyboard. It is designed to contain two lines of coding which must be punched simultaneously. This is necessary because the sequence and interpolator mechanisms, though radically different in operation, in reality are made of the same mechanical components. One numerical value in a functional tape occupies the same amount of space as two lines of control tape coding. The device

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Design and construction of the automatic sequence controlled calculator was begun in 1939 at Endicott, N. Y., and continued until August 1944, when the machine was presented formally to Harvard University by T. J. Watson, president, International Business Machines Corporation. Commander Aiken wishes to express his appreciation to Mr. Watson for the support of International Business Machines Corporation during the years of development of the calculator and further to B. M. Durfee, F. E. Hamilton, and C. D. Lake, who, together with Commander Aiken, were coinventers of the machine. The relays, counters, cam contacts, typewriters, card feeds, and card punch employed in the calculator are all standard parts of tabulating machinery as constructed by International Business Machines Corporation.

The opinions or assertions contained in this article are the private ones of the writers and are not to be construed as official or as reflecting the views of the Navy Department or the naval service at large. Material for the article has been adapted largely from "The Manual of Operation of the Automatic Sequence Controlled Calculator," *Annals* of the Computation Laboratory of Harvard University, Harvard University Press, Cambridge, Mass., volume 1 1946. Permission to use this material has been granted.

Table I

Operation	Seconds	Cycles
Addition	0.3	1
Subtraction	0.3	1
Multiplication	6.0	20
Division	11.4	38
Log$_{10}$ x	72.6	242
10^x	61.2	204
Sin x	60.0	199

Figure 1. Typewriters, card feeds, and card punch

of setting up two lines of control tape coding per punching operation makes it possible to punch sequence control tapes and functional tapes with one and the same manual punch.

Figure 5 shows a short section of control tape. (The coding corresponds to the first ten lines of the main control tape given in the example in Table IV.) As in the case of value and functional tapes, the control tape must be read upwards. As the control tapes deal with operations only, they represent the solution of a mathematical situation independent of the values of the parameters involved. Hence, such control tapes as are of general application are preserved in the tape library for future use. Functional and value tapes of general interest likewise are preserved.

When a problem is referred to the computation laboratory, the first step in its solution is that taken by the mathematician who chooses the numerical method best adapted to computation by the calculator. Since the mathematician cannot always be present while the calculator is running, instructions must be prepared to guide the operating staff. These must include switch settings, the list of tapes to be used, plugging instructions, manual resets, information concerning checks, starting, stopping, and rerun instructions. The instructions for the plugging of the functional units usually are given in the form of diagrams. The manual resets may include the clearing of both functional and storage counters. Above the sequence mechanism are the 72 push buttons which permit manual resetting of each of the storage counters. Directly below the reset buttons and above the sequence mechanism, is a constant register which exactly duplicates one of the 60 switches. Because this register frequently is used to provide the increment of the independent variable, it is known as the independent variable switch. Further, because it is located conveniently near the sequence mechanism, this switch is particularly useful in testing the various units of the calculator.

The main sequence control is equipped to advance the tape, step by step, normally at a rate of 200 steps per minute, unless one of the subsidiary sequence controls is directed by the coding to take over command of the calculator temporarily. In this case, the control tape is stopped until the subsidiary sequence control has finished its operation and signals the main sequence control to continue operation.

The normal step rate of the sequence tape, then, does not give a good estimate of the speed of the calculator. This may be given better by citing the time required for various operations. When computing with 23 digits and operating decimal point*between columns 15 and 16, division plugged for 16 comparisons, the maximum operation times are as shown in Table I. All of the times cited in Table I include the time required to transfer the arguments to the functional units and to deliver the results for further computation. The time required for all operations, except addition and subtraction, may be shortened by reducing the accuracy of the computation. Obviously, the only way to state the relative speed of the calculator is to solve a problem first by manual methods and then by use of the machine. Such an estimate has been made and apparently the machine is nearly 100 times as fast as a well-equipped manual computer. When it is borne in mind that a computer can work little more than six hours a day before fatigue causes him to produce a prohibitive number of errors, it becomes clear that, operating on a 24-hour schedule, the calculator may produce as much as six months' work in a single day.

PLANNING THE COMPUTATION

In most cases there are several methods of adapting a problem for machine computation. After all methods of attack have been considered, one usually will show distinct advantages with regard to speed and ease of operation and reliability of the checking procedures employed.

Since machine time is extremely valuable, the first

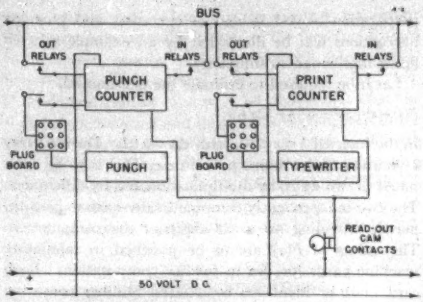


Figure 2. Print and punch counters

consideration in planning a sequence tape is to reduce the computation time to a minimum consistent with the required accuracy. However, a fine balance must be maintained between computation time and the ensuing complexity of the coding. The conservation of one or two cycles of machine time, for example, will not be profitable if it means that the counters containing essential parts of a computation must be reset before the results are checked.

The second consideration in planning a computation is ease of operation. If switches must be altered or sequence tapes interchanged at relatively short intervals of time, these operations will constitute not only a loss of time, but also a source of error.

Ease of rerunning a computation in the wake of an error and the possibility of computing for specific values of the independent variables also must be considered. Machine failures occur from time to time. The amount of time consumed in detecting the source of an error is usually dependent upon the complexity of the coding. The time required to resume operation after an error, which is dependent upon the number of manipulations the attendant must perform, should be reduced to a minimum in a well planned sequence tape.

CHECKING FOR ERRORS

Finally, of paramount importance in the design of a sequence control tape, are the checks on the computation. These must insure positive proof that the output values obtained are precisely those required and that they are correct to the desired accuracy. Four classes of errors must be taken into account:

1. Errors inherent in the mathematical formulas.
2. Errors produced by a repetition of the four fundamental operations of arithmetic.
3. Errors introduced by manual operations.
4. Errors resulting from mechanical or electrical failures within the calculator itself.

The errors inherent in the mathematical formulas must be evaluated during the preliminary analysis before the coding is begun. Decisions must be made regarding the number of terms of an infinite series to be retained, the number of times an iterative process must be applied, and the order of interpolation required. These decisions are dependent upon the interval and increment of the independent variable and the accuracy desired in the computed results.

The loss of accuracy due to the repetition of the four basic arithmetical operations in a finite digital calculator must be subjected to a detailed analysis. For each operation, the maximum error must be assumed and the error of the final result computed. The simple expedient of using a certain number of extra computing columns, in general, will nullify errors from this source. Thus, the choice of the operating decimal position will be dictated in part by the number of extra columns so allowed.

The two major sources of human error, incorrect switch settings and incorrect plugging, are perhaps the most serious of all. If the mathematical nature of a problem permits a check of the final results, independent

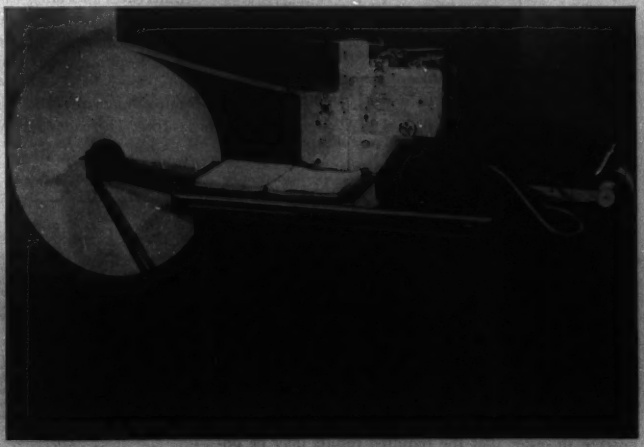


Figure 3. Manual punch

of the method of computation, the errors of the manual operations will be detected. If, however, the only checks which may be applied are those of an operational character; that is, substantiating the fact that the desired sequence of operations has been performed correctly by the calculator, such errors as incorrect switch settings may not be detected. Hence meticulous pre-

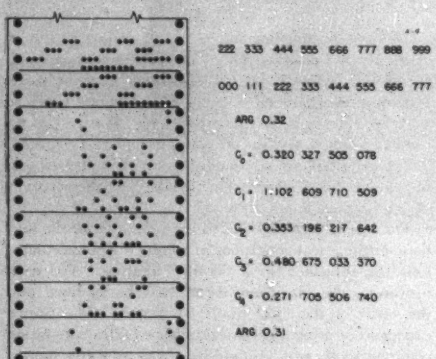


Figure 4. Value and functional tape coding

cision on the operator's part and careful checking of all manual operations are essential.

Mechanical and electrical failures within the calculator itself are the final source of errors which must be checked. If a problem is coded properly, either operational or end result checks must be provided to detect such failures. In no case must the calculator be permitted to run more than 20 minutes without checks.

It is often necessary to make preliminary computations and to set certain values in storage counters before a computation is begun. In such an event a starting tape, which usually is a short 2-ended control tape, is used.

OPERATING INSTRUCTIONS

Every sequence control tape must be accompanied by operating instructions. These instructions must be sufficiently complete to enable an experienced attendant to set up the problem and operate the calculator. Complete plugging instructions also must accompany every tape.

In the preparation of control tapes and operating instructions, a standard practice is necessary since the operation of large scale calculating machinery on a continuous basis is, of necessity, a group enterprise. The methods and techniques employed must be standardized in order that the required results may be obtained with a minimum of special instructions. The preparation of coding and of operating and plugging instructions will be illustrated by an example selected for its mathematical simplicity.

Let it be required to evaluate the polynomial,

$$F(x)=x^4+3x^3-3x^2/4-22x+3$$

in the interval $5\leq x\leq 10$, with $\Delta x=0.01$. During every revolution of the main control tape, $F(x)$ is to be computed in two ways, by multiplication and by differences. The two independently computed values are to be compared, providing an exact check of the computation. The values of $F(x)$ are to be punched in tabulating machine cards for use in further computation. Each card must be identified by a serial number consisting of the argument, x_n, punched with its decimal point between card columns 75 and 76 and a one in the 80th card column. It is not required to print the values of $F(x)$. The tape is to be designed so that it may be rolled back and rerun without any additional manipulations. The starting tape is to be designed so that it may be used to re-establish the computation for any arbitrary value of the argument. If $F(x)$ is written in the form

$$F(x)=(((x_n+3)x_n-3/4)x_n-22)x_n+3$$

it should be clear that only three multiplications will be required to evaluate the given polynomial. In general a polynomial of nth degree will require not more than n multiplications. The constant coefficients will be supplied from switches. Since $F(x)\leq 2\times 10^4$ in the interval under consideration, the operating decimal point may be assumed to lie between columns 15 and 16. Suppose five values of the function, F_{n-5}, F_{n-4}, F_{n-3}, F_{n-2}, F_{n-1}, to be available in punched cards. The starting tape is to be designed to feed these five cards, and compute the differences associated with the argument x_{n-1}. A switch containing Δ^4F will be used to check the fourth difference as computed by the starting tape. Therefore, before beginning the computation with the calculator, $F(x)$ for $x=4.95, 4.96, 4.97, 4.98, 4.99$, must be computed manually and punched in tabulating machine cards. Thereafter $F(x)$ will be punched in cards by the

Table II. Switch Settings

Number	Code	Setting and Purpose
1	741	$\Delta x=1$ in 14th machine column; increment of argument for computing
2	742	$\Delta x=1$ in 4th machine column; increment of argument for punch card serial numbers
4	743	1 in 1st machine column; punch card code for $F(x)$; zero check tolerance
5	7431	0.75
6	7432	22
7	74321	3
8	75	0.000 000 24
9	751	x_{n-1} = argument for computing; decimal point between columns 15 and 16; used in starting tape only
10	752	$x_{n-1}+3$; decimal point between columns 15 and 16; used in starting tape only
11	7521	x_{n-1} = argument for punch card serial numbers; decimal point between columns 5 and 6; used in starting tape only

main control tape. Hence, in the event of a machine error, any five successive values of the function, known to be correct, may be used to re-establish the computation with the aid of starting tape.

The main control tape is to be designed so that the value of the function and its differences computed in the $m-1$st revolution of the tape will be used in the mth revolution of the tape to compute the next succeeding value of the function and its differences. The switch settings, coding, operating and plugging instructions for the solution of the example are shown in Tables II, III, and IV.

OPERATING INSTRUCTIONS

1. Set switches as listed. Punch the values set in the switches and compare the punched values with the list of switch settings.

2. The quantities punched under control of the main tape are the values of $F(x_n)$. Each card is to be identified by a serial number consisting of the argument, x_n, punched in card columns 74–77 and a one, the code for $F(x)$, in card column 80. All cards punched are to be placed in the drawer provided for this purpose.

3. Five cards, labeled "starting cards," must be placed in card feed 1. These cards are identified by the serial numbers 495,001, 496,001, 497,001, 498,001, and 499,001.

4. Run starting tape. When cards run out, turn off card feed control switch and restart calculator. If the starting tape is completed correctly the sequence mechanism will stop on a blank line of tape.

5. If the check, on line 35 of the starting tape, fails, the calculator will stop on line 36, reading (1, 1, 7). The starting cards must be refed and the starting tape rerun. If the check continues to fail the counters used in the difference computation (counters 1 through 15) and switch 8 must be tested.

6. Run main control tape. If no failures occur, continue run-

Table III

Starting Tape	Line Number	A	B	C
Reset counter 1	1	1	1	7
F_{n-3} to counter 1 from card feed 1	2		1	7632
Reset counter 2	3	2	2	7
F_{n-4} to counter 2 from card feed 1	4		2	7632
Reset counter 3	5	21	21	7
F_{n-2} to counter 3 from card feed 1	6		21	7632
Reset counter 4	7	3	3	7
F_{n-3} to counter 4 from card feed 1	8		3	7632
Reset counter 8	9	4	4	7
F_{n-1} to counter 8 from card feed 1	10		4	7632
Reset counter 9	11	41	41	7
F_{n-1} from counter 8 to counter 9	12	4	41	7
$-F_{n-1}$ from counter 4 to counter 9; counter $9=\Delta F_{n-2}$	13	3	41	732
$-F_{n-2}$ from counter 3 to counter 4; counter $4=\Delta F_{n-2}$	14	21	3	732
$-F_{n-4}$ from counter 2 to counter 3; counter $3=\Delta F_{n-4}$	15	2	21	732
$-F_{n-5}$ from counter 1 to counter 2; counter $2=\Delta F_{n-5}$	16	1	2	732
Reset counter 10	17	42	42	7
ΔF_{n-1} from counter 9 to counter 10	18	41	42	7
$-\Delta F_{n-1}$ from counter 4 to counter 10; counter $10=\Delta^2 F_{n-1}$	19	3	42	732
$-\Delta F_{n-4}$ from counter 3 to counter 4; counter $4=\Delta^2 F_{n-4}$	20	21	3	732
$-\Delta F_{n-5}$ from counter 2 to counter 3; counter $3=\Delta^2 F_{n-5}$	21	2	21	732
Reset counter 11	22	421	421	7
$\Delta^2 F_{n-1}$ from counter 10 to counter 11	23	42	421	7
$-\Delta^2 F_{n-4}$ from counter 4 to counter 11; counter $11=\Delta^2 F_{n-4}$	24	3	421	732
$-\Delta^2 F_{n-5}$ from counter 3 to counter 4; counter $4=\Delta^2 F_{n-5}$	25	21	3	732
Reset counter 12	26	43	43	7
$\Delta^2 F_{n-1}$ from counter 11 to counter 12	27	421	43	7
$-\Delta^2 F_{n-4}$ from counter 4 to counter 12; counter $12=\Delta^2 F_{n-3}$	28	3	43	732
Reset counter 5	29	31	31	7
$\Delta^2 F$ from switch 8 to counter 5	30	75	31	7
$-\Delta^2 F_{n-3}$ from counter 12 to counter 5	31	43	31	732
Reset check counter 72	32	74	74	7
Zero check tolerance from switch 4 to check counter 72	33	743	74	7
$\lvert\Delta^2 F-\Delta^2 F_{n-3}\rvert$ to check counter 72	34	31	74	71
Check; reset check counter 72	35	74	74	64
Reset counter 1	36	1	1	7
x_{n-1} from switch 9 to counter 1; argument for computing	37	751	1	7
Reset counter 2	38	2	2	7
$x_{n-1}+3$ from switch 10 to counter 2	39	752	2	97
Reset counter 64	40	7	7	7
x_{n-1} from switch 11 to counter 64; argument for punch card serial number	41	7521	7	7

Table IV

Main Control Tape	Line Number	A	B	C
Δx to counter 1; counter $1=x_{n-1}+\Delta x=x_n$	1	741	1	7
Δx to counter 64; counter $64=x_{n-1}+\Delta x=x_n$	2	742	7	7
Δx to counter 2; counter $2=x_{n-1}+\Delta x+3=x_n+3$	3	741	2	7
x_n+3 to MC re-run line	4	2	761	7
Reset counter 12	5	43	43	7
Reset counter 13	6	431	431	7
x_n to MP	7	1		7
Reset counter 14	8	432	432	7
Reset counter 15	9	4321	4321	7
Reset counter 3	10	21	21	7
-0.75 to counter 3	11	7431	21	32
$(x_n+3)x_n$ to counter 3; counter $3=(x_n+3)x_n-0.75$	12		21	7
$(x_n+3)x_n-0.75$ to MC	13		21	761	7
F_{n-1} to counter 12	14		4	43	7
ΔF_{n-1} to counter 13	15		41	431	
x_n to MP	16		1		7
$\Delta^2 F_{n-1}$ to counter 14	17		42	432	7
$\Delta^3 F_{n-4}$ to counter 15	18		421	4321	7
Reset counter 4	19		3	3	7
-22 to counter 4	20	7432	3	32
$((x_n+3)x_n-0.75)x_n$ to counter 4; counter $4=((x_n+3)x_n-0.75)x_n-22$	21		3	7
$((x_n+3)x_n-0.75)x_n-22$ to MC	22		3	761	7
$\Delta^4 F_{n-4}$ to counter 15; counter $15=\Delta^3 F_{n-3}$	23		75	4321	7
$\Delta^3 F_{n-1}$ to counter 14; counter $14=\Delta^2 F_{n-3}$	24		4321	432	
x_n to MP	25		1		7
$\Delta^2 F_{n-1}$ to counter 13; counter $13=\Delta F_{n-1}$	26		432	431	7
ΔF_{n-1} to counter 12; counter $12=F_n$	27		431	43	7
Reset counter 5	28		31	31	7
3 to counter 5	29	74321	31	
$(((x_n+3)x_n-0.75)x_n-22)x_n$ to counter 5; counter $5=F_n$	30		31	7
F_n to punch counter	31		31	753	
Reset counter 6	32		32	32	7
F_n by multiplication to counter 6	33		31	32	7
$-F_n$ by differences to counter 6	34		43	32	732
Zero check tolerance to check counter 72	35	743	74	7
$\lvert F_n-F_n\rvert$ to check counter 72	36		32	74	71
Check; reset check counter 72	37		74	74	64
Reset counter 6	38		32	32	7
F_n from punch counter to counter 6	39	863	32	7
$-F_n$ to counter 6	40		31	32	732
Zero check tolerance to check counter 72	41	743	74	7
$\lvert F_n-F_n\rvert$ to check counter 72	42		32	74	71
Check; reset check counter 72	43		74	74	64
Reset counter 8; initiate punching	44		4	4	751
Reset counter 9	45		41	41	7
Reset counter 10	46		42	42	7
Reset counter 11	47		421	421	7
F_n to counter 8	48		43	4	
ΔF_{n-1} to counter 9	49		431	41	7
$\Delta^2 F_{n-1}$ to counter 10	50		432	42	7
$\Delta^3 F_{n-1}$ to counter 11	51		4321	421	7
x_n for serial number to punch counter	52		7	753	
1 in 1st machine column to punch counter	53		743	753	
Initiate punching	54				75
	55				87

ning until the card for $F(9.99)$ has been punched, then press stop key.

7. If the check on line 37 of the main tape fails, the tape must be rolled back to line 4, marked "rerun line," and the computation repeated.

8. If the check continues to fail, the computation should be re-established using the following procedure for x_0:

(a). Five cards from those punched under control of the main tape must be placed in card feed 1; these cards are identified by the arguments x_{0-5}, x_{0-4}, x_{0-3}, x_{0-2}, x_{0-1}, in that order, punched in card columns 74–77, and a one in card column 80.

(b). Switches 9, 10, and 11 must be set to the values indicated in the switch list.

(c). The starting procedure must be repeated and the computation continued under control of the main tape.

9. Repeated failure of the check under the roll-back procedure of instruction 7 but correct operation under the procedure of instruction 8 probably indicates that the difference computation is the source of error.

10. If it is desired to run the computation for any arbitrary value of the argument, the procedure of instruction 8 may be used.

11. The maximum time for each revolution of the control tape may be computed as follows:

Accumulate arguments	3
Three multiplications	30
Check procedures	12
Punching $F(x)$	10
Punching serial number	3
	58 cycles = 17.4 seconds

12. The first card punched under control of the main sequence tape will be $F(5.00) = 874.25$ with the serial number 500,001.

PLUGGING INSTRUCTIONS

1. Plug the multiply unit for the standard position of the operating decimal point as shown in Figure 6.

2. Plug the card punch direct and for serial numbers as specified.

3. Plug card feed 1 direct.

Nearly two years have passed since the operation of the calculator was begun as a project of the United States Navy. During this time many problems have been solved relating to nearly every branch of physics and engineering. The problems solved include:

1. The tabulation of functions of a real variable.

2. The subtabulation of functions.

3. The tabulation of functions defined by formulas involving empirical variables.

4. The tabulation of functions of a complex variable.[1]

5. The solution of systems of linear algebraic equations.

6. Statistical analyses.

7. The determination of zeros of functions.

8. The evaluation of definite integrals.

9. The solution of systems of ordinary differential equations.

10. The solution of partial differential equations.

From time to time, the solution of these problems has required permanent changes in the wiring of the calculator, and the inclusion of new features, many of which have improved its operation greatly. Such improvements and alterations are still in process of development. As a result, this article represents the standard procedure of the Computation Laboratory as of the fall of 1945.

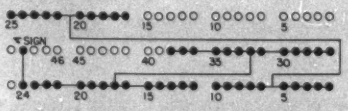
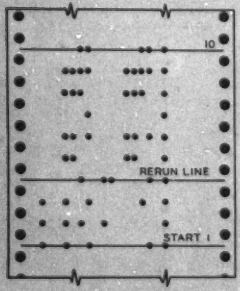


Figure 6. Multiplication plugging diagram



OUT	IN	MISC
21	21	7
4321	4321	7
4321	4321	7
1		7
431	431	7
43	43	7
2	761	7
741	2	7
742	7	7
741	1	7
A	B	C

Figure 5. Control tape coding

This discussion of the calculator and of the techniques used in its operation is all too brief. However, a description of the calculator including details of its circuits, the coding and plugging procedures, and methods of solution of problems are included in its manual of operation.[2]

The design and construction of the calculator was begun in 1939 and, almost immediately upon its completion in 1944, it was placed in operation by the Bureau of Ships of the United States Navy where work was continued until January 1946, when the project was transferred to the Bureau of Ordnance. With regard to the operation of the machine throughout the past two years, many of the operating techniques described in this article, written at the request of Professor Chester L. Dawes of Harvard University, resulted from the work of the staff of the computation project. In particular, Lieutenants (junior grade) R. V. D. Campbell and R. M. Bloch have made important contributions in the field.

REFERENCES

1. Tables of the Modified Hankel Functions of Order One-Third and of Their Derivatives, *Annals* of the Computation Laboratory of Harvard University, Harvard University Press, Cambridge, Mass., volume 2, 1945.

2. The Manual of Operation of the Automatic Sequence Controlled Calculator, *Annals* of the Computation Laboratory of Harvard University, Harvard University Press, Cambridge, Mass., volume 1, 1946.

INSTITUTE ACTIVITIES

Seattle Section Is Host to First Postwar Pacific Coast Meeting

The Pacific Coast meeting was held in Seattle, Wash., August 27–30, 1946, with headquarters in the Olympic Hotel. A well-balanced program was offered, comprised of nine sessions, including a student session and a session devoted to a discussion on the organization of the engineering profession, interspersed with inspection trips, a golf tournament, and social events for both men and women. Judged by the many enthusiastic comments received, the meeting was highly successful. The total attendance of 562 was a record for Pacific Coast meetings and more than double the attendance at the last meeting held in Seattle in 1935.

Technical sessions were on atomic power, central stations, industrial and railroad problems, aviation, power systems, and communication. Many of the papers presented dealt with problems of particular interest to West Coast members, where transmission lines are long and large blocks of hydroelectric power are concentrated.

OPENING SESSION

The meeting was opened by J. Hellenthal (M '23) general chairman, who introduced William F. Devin, mayor of Seattle. A cordial welcome was extended by the mayor, who referred briefly to the history of the city and expressed hope for a successful meeting. Responses to the welcome were made by Vice-President Charles F. Terrell (M '18) and President J. Elmer Housley (F '43). In conclusion, Vice-President Terrell stated that the foregathering was to review the changes brought about by the war and to take stock of what lies ahead.

RESPONSE BY PRESIDENT HOUSLEY

President Housely paid tribute to the speakers, Past Vice-President C. B. Carpenter (F '44), and the spirit of hospitality shown in the Pacific Northwest. He referred to the industrial development, natural resources in the area, and the well-known valuable contributions which its industries made to the war effort and victory.

Speaking on the industry with which he is most familiar, President Housley explained that just before and during the war the Aluminum Company of America embarked on an expansion program entirely self-financed and in addition undertook, without fee or profit, the building and operation of some $500,000,000 worth of aluminum plants for the government. He stated that the large smelting plant in Vancouver with an original capacity of 30,000,000 pounds a year since has been increased fivefold. He assured the meeting that the aluminum industry in the Pacific Northwest was there to stay, and he was glad to know that competitors would keep in operation smelting plants at Troutdale, Oreg., and Spokane, Wash., as well as the sheet rolling mill at Spokane. In the building of these plants for the government Alcoa put into them all of the "know-how" of nearly 60 years of the aluminum business.

As further concrete evidence that the industry was in the region to stay President Housley cited the continuance of experiments on processes for the use of low-grade laterite ore found in Oregon and active plans to bring high-grade limestone from Alaska into the Pacific Northwest area for use in the manufacture of alumina and for other important purposes.

In conclusion, President Housley spoke of the other engineering developments in the Northwest, including the early and recent hydroelectric developments, transportation, mining, steel mills, saw mills, and the aviation industry. He urged members to take back with them the enthusiasm engendered by the meeting, the story of engineering progress told at the technical sessions, and most of all the encouragement of professional development.

ATOMIC POWER

One of the highlights of the meeting was an address on "Development of Atomic Power" by Bruce R. Prentice of the General Electric Company. This was particularly fitting on the eve of the taking over of the Hanford plant for the production of plutonium by the General Electric Company under a broad program of research and development of atomic energy for power.

Recognizing the general interest in knowing when atomic power for commercial use will become a reality, Mr. Prentice pointed out that predictions mean little if the stage of development is not also clearly defined. Though he admitted that charting the course of development at this time is impossible, he noted that intensive development is under way at the General Electric Company and Clinton Laboratories, Oak Ridge, Tenn. The Clinton project may produce moderate amounts of power in two years. With this date as the first milestone, Mr. Prentice predicted rapid expansion, improvement, and changes, and that in perhaps 25 years atomic power should be in widespread use on many different applications.

By alide the schematic structure of the uranium pile was shown, and the control of the chainlike reaction by means of positioning boron or cadmium control rods through the pile was explained. Boron or cadmium readily capture the slow neutrons. Other important factors were discussed, such as what determines the size of the pile, poisoning effects within the pile, radiation stability within the pile, shielding to stop the neutron and gamma rays, and safety to prevent explosion.

With respect to the engineering problems six possible nuclear power systems were considered. Two of these systems, using liquid convection or evaporation of liquid to vapor, employ heat exchangers which also would have to be shielded. One of the systems, to obtain electricity directly from the pile, would depend upon radical new invention. Controls probably would have to be automatic, much faster, and integrated with considerable instrumentation to measure various quantities. The matter of heat transfer also presents engineers with challenging problems, such as getting the heat out of the pile just as fast as possible. A considerable amount of development work would be needed to find fluids, including liquid metal alloys and gases, which will not change their properties in operation. Materials must withstand high temperatures, and appreciable erosion could not be permitted as replacement of parts within a pile would be extremely difficult. Transmutations of the fluid, pipes, and so forth, may complicate greatly a solution to the materials problem.

On the economics side Mr. Prentice likened the cost of fuel to an investment which would last for a considerable period of time, and he mentioned the need to reclaim the critical materials from the ash.

He mentioned three limitations to all applications. First the shields probably will continue to be both large and heavy. Second, the cost of fuel, magnitude of initial investment, combined with a considerable

Analysis of Attendance at 1946 Pacific Coast Meeting

Classification	Seattle	District 9*	District 8	District 10	Miscellaneous	Totals
Members	159	88	55	9	20	331
Men guests	55	13	8		8	84
Women guests	43	40	32	4	10	129
Students	15	3	10			28
Totals	272	144	105	13	38	572

* Outside of Seattle Section territory.

cost of refueling as well as the handling and reclaiming of critical materials, may limit application greatly. Third, the health hazards, although they can be safeguarded, will require constant vigilance and much instrumentation, which will influence the design of atomic power plants. Applications were forecast in the following order. The first application probably would be naval and merchant marine ships, where long life of fuel and the small volume would probe attractive. The second application might be for mining and other activities in remote places, where it is difficult to obtain power supply. The third use may be for emergency power plants. Fourth would be use by the public utilities, depending on economic and national policy factors. Fifth would be the application to railroads, aircraft, and other means of transportation, which was put last due to shielding limitations and to a lesser extent the investment, maintenance, and safety limitations previously discussed.

In conclusion, Mr. Prentice explained that the address would not be submitted for publication, because he had largely drawn his material from articles by H. A. Winne, Doctor C. G. Suits, and Doctor Kenneth H. Kingdon, published in the Edison Electric Institute *Bulletin* for June 1946.

In the remainder of the session two papers were presented, which described "Columbia River Power" and "Power System Development for Service to the Hanford Plutonium Plant."

STUDENT CONFERENCE LUNCHEON

The student conference luncheon, held Wednesday, August 28, was well attended by Institute officers, counselors, and representatives of the various Branches. Among the officers present were President Housley, Vice-President F. F. Evenson (M '29), Secretary H. H. Henline (F '43), and Director W. C. Smith (F '40). Secretary Henline spoke briefly, expressing pleasure at seeing the group gathered together on the 20th anniversary of the first Student Branch conference, which was held at Salt Lake City, and also marking his 20th year at Institute headquarters. He referred to the difficulties of operation of the Student Branches during the depression and the war years and hope was expressed that with a fresh start the Student Branch activities would meet with great success.

President Housley expressed pleasure at being with the group, saying that he always was interested in the students and members of the faculties in educational circles. He said it was important that the students and counselors work together in the Institute and with industry. The question was raised as to why the colleges do not prepare more students for the management of industry. Engineers should be just as well prepared to take over the management of a bank as a lawyer. He also expressed belief that a little too much glamor and fascination had been attached to the subjects of electronics and atomic energy, as in the final analysis a high percentage of the engineering employment would be found in the 60-cycle field. In conclusion President Housley expressed hopes that our neighbors across the seas would work with use for better living standards and organization within those countries.

Different views were held by several of the Student Branch counselors in regard to the joint operation of Student Branches. On the one hand Professor A. L. Albert (F '41) and others believed that AIEE would lose its identity through the broadening of activities and the holding of joint Student Branch meetings. Financially, it was cited, the Branches are a liability to the Institute, in that the $3 dues do not cover the cost of operation and the publications. On the other hand Professors F. E. Terman (F '45), P. L. Morton (M '43), and others were in favor of combined operation, as it tended to reduce the competition and distinction between the fields of communication and electrical engineering. Student Branch chairmen or representatives from several of the Branches briefly reported on the Student Branch activities of the Branches in Districts 8 and 9. Dean E. W. Schilling (F '44) chairman of the committee on Student Branch activities, District 9, presided.

BANQUET

The banquet was held Thursday, August 29, and provided an enjoyable evening to many members and guests. Music was supplied by the Olympic String Orchestra and Mr. Moody entertained with sleight-of-hand tricks and Arthur Anderson with impersonations. Vice-President Terrell was toastmaster.

After the dinner Secretary Henline presented the prize for best paper in the North West District to E. C. Goodale (M '45) and J. I. Holbeck (M '36) for their paper entitled "Field Determination of Current Transformer Errors by the Secondary-Voltage Method," which was presented at a meeting of the Portland Section, April 3, 1945. He also presented the prize for best paper in the Pacific District to J. V. Kresser (M '43) for his contribution entitled "Characteristics and Limitations of Transformer Connections," which was presented at a meeting of the San Francisco Section, November 16, 1945.

The banquet was addressed by President Housley, who complimented the committee on the success of the meeting, the scope of the technical program, and the value of the social events. Reference also was made to the abundance of opportunity held by the Northwest for the younger generation, in view of the richness of its natural resources. The history and rapid growth of the Institute was surveyed briefly and President Housley expressed hope that the gain in one direction would not become a loss in another. In taking stock of the situation he explored the relation between science and industry and referred to the seven major developments that took place during the war in the realm of physics, electronics, chemistry, metallurgy, aerodynamics, electric machinery, and power systems. In conclusion, he stated that the AIEE is the universal society for the consideration of these new developments in their relation to electrical engineering.

Prizes for the golf tournament, held on the course of the Inglewood Golf and Country Club on the previous day were presented by C. R. Kingsbury (M '39) chairman of the golf committee. The winner of the Fiaken cup was George Palo (M '41) of Seattle, who was presented with a leather golf bag. Second low net was J. W. Ferguson (A '40), who received a golf jacket, and third low net was W. S. Hill (M '20), who received a sport shirt.

First low gross score was made by J. C. Henkle (M '36) of Portland; second low gross, W. J. Mosley (A '43) of Seattle; and third low gross K. J. McLean (A '43) of Seattle. These winners respectively were presented with golf shoes, a chipper, and a lightweight canvas golf bag. Other prizes were presented for the nonmember contest, as well as kicker's handicap, long drives, closest to the pin, and for birdies.

ORGANIZATION OF THE ENGINEERING PROFESSION

The session providing opportunity for discussion on the organization of the engineering profession was highly successful. The subject was introduced by Vice-President Carpenter who presided and who explained that the board of directors had authorized that a study should be made by the committee on planning and co-ordination, of which Vice-President J. F. Fairman (F '35) is chairman. The committee has appointed two subcommittees to carry out the work,—the professional activities subcommittee, T. G. LeClair (F '40) chairman, and the technical activities subcommittee, M. D. Hooven (F '44) chairman. Discussers were requested to use their Section affiliation.

The progress made so far was reviewed by Vice-President Fairman, who explained that the procedure was by method of trial and observation. With the aid of slides the four plans of organization developed by the professional activities subcommittee were reviewed and the questionnaire form, although not perfect, was considered a satisfactory vehicle for evaluation.

The meeting was open for discussion, and much enthusiasm was shown by members and Section representatives on the West Coast, who presented specific problems in their localities and stated reasons for the preference of one or more of the several plans. In general, most speakers expressed satisfaction with the technical activities, but the discussion presented many varied problems on the professional activities side. The results obtained from the questionnaire will prove most valuable to the committee on planning and co-ordination in carrying on the work.

TECHNICAL SESSIONS

The technical sessions were of broad scope and well attended, and keen interest was manifested in both the presentations of the papers and discussion which followed. Besides the session on atomic power, other high spots of the program consisted of an address in the aviation session "Air Industrial Preparedness Planning" by Lieutenant Colonel Bert R. Kuss, United States Army Air Corps. A feature of the communica-

tion session consisted of a review of present status of television, which was presented by R. D. Kell of RCA Laboratories. Mr. Kell demonstrated the remarkable pickup of the new camera tube, called an Image Orthicon, which is more than 100 times as sensitive as the iconoscope, and under some conditions more than 1,000 times as sensitive.

ENTERTAINMENT

Besides the banquet, a reception to the president was held on the first evening of the meeting, and on the second evening as many members as could be accommodated attended a play, "Pomeroy's Past," at the Pent House Theatre at the University of Washington. During the meeting a number of the women were entertained on an automobile tour of the city and the environs, a bridge luncheon at the Seattle Tennis Club, and a boat cruise on Lake Washington.

INSPECTION TRIPS

Many members who attended the meeting took advantage of the various inspection trips and visited the Puget Sound Naval Ship Yard, Seattle Naval Station, Boeing Aircraft Company, and other industrial plants, as well as the several power plants.

Aid for AIEE Committees Provided at Headquarters

As a means of fulfilling the proposal made by the AIEE board of directors at its May meeting that the headquarters staff be strengthened to increase the effectiveness of the management and administration of the Institute, an assistant to the secretary of the Institute has been added to the headquarters staff.

Charles C. Wilson (M '43) new assistant to the secretary, has the duty of assisting the technical committees. Chairman of the technical committees have been invited to communicate with Mr. Wilson regarding the types of assistance which he might extend their committees. Details of Mr. Wilson's previous career may be found on page 534 of this issue.

AIEE Subcommittee Surveys Vacuum Tube Types

In the interest of providing more reliable vacuum tubes for use in electronic instruments, the AIEE subcommittee on electronic instruments is conducting a survey among more than 400 instrument manufacturers to determine what types of special tubes should be made and what the demand would be for each of these special types. The subcommittee on electronic instruments is a joint subcommittee of the committee on electronics and the committee on instruments and measurements.

Information obtained from the survey will be tabulated, published as a committee report, and made available to all vacuum tube manufacturers, most of whom already have expressed their interest. The subcommittee then plans to formulate standards for tubes with more uniform tube characteristics, more rugged construction, better stability, longer life, lower hum, and reduced microphonic effects.

It is the desire of the subcommittee that readers of *Electrical Engineering* assist in the survey by making certain that their companies receive questionnaires.

Future AIEE Meetings

Winter Meeting
New York, N. Y., January 27–31, 1947

North Eastern District Meeting
Worcester, Mass., April 23–25, 1947

Summer Meeting
Montreal, Quebec, Canada, June 9–13, 1947

Committee for First Midwest Meeting Appointed

The committee has been appointed to make arrangements for the first AIEE Midwest meeting, which will be the fourth yearly meeting of the Institute. The first of the Midwest meetings will be held November 3–7, 1947, in Chicago, Ill. Inauguration of the Midwest meeting was approved by the executive committee of the board of directors in April 1946 upon recommendation of the committee on planning and co-ordination.

Members of the committee are:

F. H. Lane (F '37) *chairman;* Dwight L. Smith (M '27) *vice-chairman;* F. V. Smith (M '38) *secretary;* N. C. Pearcy (F '43) *treasurer;* D. L. Bement (M '44); O. W. Eshbach (F '37); J. E. Hobson (M '41); L. R. Janes (M '29); P. B. Juhnke (F '36); T. G. LeClair (F '40); J. R. North (F '41); R. R. O'Connor (M '43); R. I. Parker (M '20); and H. K. Smith (F '44).

SECTION

Illinois Valley Section Schedules Year's Meetings

The full year's schedule of meetings for 1946–47 recently was issued and distributed by the Illinois Valley Section, reflecting the interest, activity, and foresight of the officers of this new Section. Gordon H. Duff (A '45) application engineer for the Westinghouse Electric Corporation, Peoria, Ill., is the chairman of the Section's program committee. The Section was established formally June 30, 1946, with an initial membership of 47 compared with which its August 1, 1946, membership of 80 represents a 70 per cent growth.

The first of the current season's meetings was held in Peoria, Ill., September 5, and was addressed by Doctor D. E. Noble, director of research for the Galvin Manufacturing Corporation, Chicago, on the subject, "Two-Way Radio Communication With Mobile Units." The second meeting was scheduled for October 3, at Pekin, Ill., and addressed by D. R. Siewert, district superintendent of service shops for the General Electric Company, Chicago, on the subject, "Electrical Maintenance." The third meeting scheduled for October 17 at Springfield, Ill., was addressed by G. O. Paden of the engineering and service division, Westinghouse Electric Corporation, Pittsburgh, Pa., on the subject, "The Impact of Radar in War and Peace." Nine additional meetings of a similar type are listed covering programs for the remainder of the operating year.

T. A. Hopkins (A '44) electrical research engineer for the Caterpillar Tractor Company, Peoria, is the new Section chairman, and C. T. Borchelt (A '45) construction engineer for R. G. LeTourneau, Inc., is Section secretary. E. W. Stone (M '37) distribution engineer for the Central Illinois Light Company, Peoria, is chairman of the Section's printing and mailing committee which is responsible for keeping Section members informed concerning committee personnel, Section projects, and Section activities in general.

Nuclear Physics Introduces 1946–47 Season for St. Louis

The beneficial aspects of nuclear physics were discussed by Doctor A. L. Hughes of Washington University and J. T. Wilson of the Allis-Chalmers Manufacturing Company at the first meeting of the AIEE St. Louis Section for the 1946–47 season.

Doctor Hughes explained the various methods by which high energies can be imparted to particles for probing the atoms and the theory behind the Van der Graf electrostatic generator, the cyclotron, the betatron, and the linear accelerator. The advantages and limitations of each were delineated from both the economic and the scientific viewpoints.

Greater detail on the betatron was given by Mr. Wilson, who after describing its mechanism, briefly considered the possibilities of using the X rays produced by the betatron in industrial radiography and in cancer therapy.

The technical program of the St. Louis Section for the current season includes monthly meetings by its technical discussion groups on electronics, illumination, and industrial power practices. The illumination group is newly organized.

Officers of the Section for 1946–47 are:

Chairman: O. T. Farry (M '40).

Vice-Chairman: E. S. Rehagen (M '42).

Secretary–Treasurer: R. W. Gaskins (M '37).

Chairman, meetings and papers committee: O. V. Tally (M '44).

Chairman, membership committee: S. F. Joyce, Jr. (A '44).

Chairman, entertainment committee: R. W. Schoetter (M '45).

Chairman, fellowship committee: H. M. Du Phorne (A '29).

Chairman, educational committee: L. O. Campbell (M '29).

Chairman, student activity committee: D. A. Fischer (A '42).

Chairman, publicity committee: J. G. Lebens, Jr. (A '41).

27th Subsection Formed at Canton, Ohio

AIEE members in the environs of Canton, Ohio, held an organization meeting on September 4, 1946, for the 27th Subsection of the Institute, which is in the territory of the Akron Section.

The new Subsection, which has 33 members, will hold monthly meetings in Canton. Officers elected at the first meeting are:

Chairman: R. C. Wey (A '32) of the Ohio Power Company.

Secretary-Treasurer: H. E. Rue (A '39) of the Hoover Company.

Program Chairman: L. S. Steiner (A '40) of the Timkin Roller Bearing Company.

Membership Committee Chairman: George Elliott of the Hoover Company.

The Canton Subsection organization committee was composed of H. T. Welser (A '38), K. F. Sibila (A '38), and G. S. Ketter.

At a recent meeting of the governing board, the Akron Section voted to extend all possible help to the Canton group in its new venture. The members in the Canton area are reported to be enthusiastic about the enlarged facility for the expanded range of activities afforded by the formal organization of the Subsection.

PERSONAL ••••

J. F. Calvert

R. K. Honaman

W. R. Smith

John Fyfer Calvert (A '27, M '35, F '45) professor and chairman of the department of electrical engineering, Northwestern Technological Institute, Evanston, Ill., has been appointed chairman of the AIEE committee on Student Branches for 1946–47. Professor Calvert, who was born October 14, 1898, in Columbia, Mo., received from the University of Missouri the degrees of bachelor of science in 1922 and electrical engineer in 1924. He also holds the degrees of master of science (1930) and doctor of philosophy (1936) from the University of Pittsburgh. He entered the graduate student course at the Westinghouse Electric Corporation, East Pittsburgh, Pa., in 1923, and from 1924 to 1936 he was electrical engineer in the power engineering department of the company. In 1936 Professor Calvert commenced his teaching career as associate professor of electrical engineering at Iowa State College, Ames. He joined the faculty of Northwestern University in 1938 and became chairman of the department of electrical engineering at the technological institute in 1939. In 1941 and 1942 Professor Calvert was associated with the Naval Ordnance Laboratory, Washington, D. C., on various projects including construction work in Chesapeake Bay, and electrical installations at Pearl Harbor, T. H. From 1942 to 1944 he was in charge of projects at Northwestern University under contract with the Office of Scientific Research and Development. During the war he also organized the United States Naval Training School at Northwestern University and an Ultra-high Frequency School for the United States Army Signal Corps. Professor Calvert served in the United States Infantry during World War I on the Mexican border and in France. He is the author of many technical articles and holds a number of patents concerned with lightning protection of insulation and with high-voltage a-c generators. He has been active in the work of the AIEE Chicago Section and has been a member of the AIEE committee on electric machinery since 1939. He also is a member of the American Society for Engineering Education, the Western Society of Engineers, Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the American Association for the Advancement of Science.

W. R. Smith (M '18, F '30) safety engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed 1946–47 chairman of the AIEE headquarters committee. He was born in Charleston, S. C., February 23, 1885, and was graduated from Clemson Agricultural and Mechanical College in 1906 with the degree of bachelor of science in electrical engineering, receiving the degree of electrical engineer in 1928. During 1907 he was employed as secretary and assistant to the head of the engineering department at Clemson College and in 1908 entered the employ of the Hartford Suspension Company, Jersey City, N. J., as draftsman. He became manager of the company's New England office, Boston, Mass., in 1909, of its Newark office in 1911, and was placed in charge of the department of design in Jersey City in 1912. During 1913 he was salesman for the White Motor Car Company, Newark. His association with the Public Service company commenced in 1914 in the electrical construction department, and from 1917 to 1922 he was field engineer in charge of construction work. With the formation of the Public Service Production Company, Newark, in 1922, he became superintendent of electrical construction and in 1924 was appointed managing electrical engineer. In 1927 he was made assistant chief engineer and as such also was employed by the Newark branch of the United Engineers and Constructors, Inc., from 1928 to 1935. In 1936 he returned, as transmission construction engineer, to the Public Service Electric and Gas Company. Since 1938 he has been safety engineer. He has been active on the following committees: publications, co-ordination of Institute activities, Alfred Noble Prize, safety, board of examiners, award of Institute prizes, and finance. In addition he has served as chairman and as secretary of the New York Section. He has served on the National Fire Waste Council and on committees of the National Fire Protection Association and holds membership in the National Society of Professional Engineers, the Edison Electric Institute, the American Society of Safety Engineers, and the National Safety Council.

Richard Karl Honaman (A '16, M '36, F '36) director of publication, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed chairman of the newly formed AIEE committee on publicity for 1946–47. Mr. Honaman was born September 17, 1895, in Lancaster, Pa., and holds the degrees of bachelor of science (1916) and master of science (1917) from Franklin and Marshall College. After a year as instructor at Franklin and Marshall College, Lancaster, he became assistant physicist with the National Bureau of Standards, Washington, D. C., in 1917, and in 1918 was named associate physicist. In 1918 and 1919 he was also assistant professor at George Washington University, Washington. In 1919 Mr. Honaman joined the American Telephone and Telegraph Company, New York, as engineer in the department of development

J. D. Tebo

J. W. Barker

D. A. Quarles

R. L. Jones

and research, and in 1926 he was named to the inductive interference staff. He was titled assistant protection development engineer in 1930. While in this position he was chairman for the Bell Telephone System of Joint Project Committees with the Edison Electric Institute. Mr. Honaman was assigned to the staff of Bell Telephone Laboratories as protection methods engineer in 1934. During the recent war he was director of the Laboratories' school of war training, which trained more than 4,000 men and prepared instruction manuals. Mr. Honaman later was appointed assistant director of publication and in 1945 was made director. He holds a number of United States patents and is a member of the AIEE publication committee.

Reginald Lamont Jones (A '11, M '17, F '31) director of apparatus development, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed 1946–47 chairman of the AIEE committee on constitution and bylaws of which he has been a member since 1942. Doctor Jones was born in New York, N. Y., February 28, 1886. He received a bachelor of science degree in electrical engineering in 1909, a master of science degree in 1910, and a doctor of science degree in 1911, all from the Massachusetts Institute of Technology. Following a year as instructor in electrical engineering at Lowell Institute for Industrial Foremen, Boston, Mass., he became a member of the research staff of the Western Electric Company, New York, N. Y., and in 1914 was placed in charge of the transmission research department. Doctor Jones took charge of the inspection engineering department in 1923, and, when the Western Electric Company's research department became the Bell Telephone Laboratories, in 1925, he retained that position with the new company for which he organized and directed a new department to establish a scientific basis for inspection operations in factory and field. In 1927 he assumed charge of the outside plant development department, and in 1928 he was made director of apparatus development. In 1941 Doctor Jones was appointed a representative of AIEE on the Engineers' Defense Board. His society affiliations include the American Physical Society, the Acoustical Society of America, the American Association for the Advancement of Science, and the Academy of Political Science.

Donald Aubry Quarles (A '23, M '29, F '41) director of apparatus development, Bell Telephone Laboratories, Inc., has been appointed chairman for 1946–47 of the AIEE finance committee of which he has been a member since 1944. Mr. Quarles, who was born July 30, 1894, in Van Buren, Ark., received the degree of bachelor of arts from Yale University in 1916. He served as a captain of field artillery in the first World War and in 1919 entered what was then the engineering department of the Western Electric Company, New York, N. Y., which in 1925 became Bell Telephone Laboratories, Inc. He was concerned with transmission engineering research until in 1924 he was given charge of apparatus inspection engineering. He was transferred to the outside plant development department in 1928 and served successively as plant system engineer, assistant director of apparatus development (1935), and outside plant development director (1940). Later in 1940 he was titled director of transmission development and in 1944 director of apparatus development. Mr. Quarles has served on the AIEE committees on the Edison Medal, electronics, instruments and measurements, and is currently serving as an AIEE director and on the Library Board of the United Engineering Trustees. He also is serving on the board of trustees of the AIEE Retirement System. He is a member of the American Physical Society.

Julian Drenner Tebo (A '36, M '36) supervisor, machine switching laboratory, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed 1946–47 chairman of the AIEE committee on basic sciences of which he has been a member since 1937. Born July 5, 1903, in Harpers Ferry, W. Va., Doctor Tebo received the degrees of bachelor of engineering in 1924 and doctor of engineering in 1928 from Johns Hopkins University. In 1924 and 1925 he took the student training course in meter and relay operating at the Westinghouse Electric Corporation, East Pittsburgh, Pa. His association with Bell Telephone Laboratories commenced in 1928, at which time he engaged in electromagnetic design, particularly as applied to the reduction of interference between power and telephone lines. Following this he was assigned to cross bar machine switching, designing electromagnets and establishing requirements. During World War II he worked on the development and manufacture of radar and sonar devices. Active in the affairs of the New York Section, Doctor Tebo was chairman of its basic science group for 1945–46 and is chairman of the program committee for 1946–47. He has taught courses in electromagnetic design and manufacturing methods for Bell Laboratories and is a member of Sigma Xi.

Joseph Warren Barker (M '26, F '30) president, Research Corporation, New York, N. Y., has been appointed chairman of the AIEE committee on research for 1946–47. Doctor Barker was born in Lawrence, Mass., June 17, 1891, and holds several degrees from Massachusetts Institute of Technology. From 1930 to 1946 he was dean of the faculty of engineering at Columbia University, New York. Exceptionally prominent in the committee work of the AIEE, Doctor Barker has served on the following committees: production and application of light, education, Edison Medal, planning and co-ordination, Fortescue Fellowship, award of Institute prizes, and publication. He also represents the AIEE on the council of the American Association for the Advancement of Science, and the United States National Committee of the International Commission on Illumination. For a more detailed biography of Doctor Barker see the May issue of *Electrical Engineering*, page 228.

Tomlinson Fort (A '27, M '35) manager, central station department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed 1946–47 chairman of the AIEE committee on membership of which he has been a member since 1943. Mr. Fort was born December 9, 1902, in Atlanta, Ga., and was graduated from the New Mexico College of Agriculture and Mechanic Arts with the degree of bachelor

of science in 1923. After completing the graduate student course at the Westinghouse company in 1924, he was named application engineer in the power department. He was transferred to Albany, N. Y., as engineer and salesman in 1927 and in 1930 was given charge of the Albany office. The following year he became central station representative for the company in New York, N. Y., and returned to East Pittsburgh in 1940 as assistant manager of the central station department. He was appointed manager of the department in 1944. Mr. Fort has been active in AIEE Section activities and is a registered professional engineer in New York State.

George S. Whitlow (A '29, M '39) electrical engineer, Union Electric Company of Missouri, St. Louis, has been appointed chairman for 1946–47 of the AIEE committee on automatic stations of which he has been a member since 1941. Born in Hamburg, Ark., August 8, 1902, Mr. Whitlow was graduated from the University of Arkansas with the degree of bachelor of electrical engineering in 1924. He entered the General Electric Company test course in Schenectady, N. Y., in 1924 and was made head of automatic switchgear testing at the Schenectady and Philadelphia, Pa., plants in 1926. He was transferred to Fort Wayne, Ind., where he continued to work on automatic switchgear and while in this position supervised installations in Havana, Cuba. He was sent to St. Louis as application engineer for the company in 1928. In 1941 Mr. Whitlow joined the Union Electric company. He is the author of several technical papers.

Donald Elliott Moat (A '29, M '39) district manager, technical division, Leeds and Northrup Company, Cleveland, Ohio, has been appointed 1946–47 chairman of the AIEE committee on transfers of which he has been a member since 1945. Mr. Moat was born January 22, 1902, in Slingerlands, N. Y., and received the degree of mechanical engineer from Rensselaer Polytechnic Institute in 1924. After a period in the apprentice course and planning division of the Westinghouse Electric Corporation, Philadelphia, Pa., Mr. Moat entered the training course of Leeds and Northrup Company, Philadelphia, in 1925. At first assigned to service and sales work in Philadelphia, he later was transferred to Cleveland as district manager of the technical division. He is registered as a professional engineer in Ohio.

C. C. Wilson (M '43) has joined the AIEE headquarters staff in New York, N. Y., as assistant to the secretary to assist the technical committees. Mr. Wilson was born July 31, 1912, in Pueblo, Colo. He received the bachelor of science degree in engineering from Trinity College in 1933 and the bachelor of science degree in electrical engineering from Massachusetts Institute of Technology in 1935. He became an assistant in the electrical laboratory of the Ward Leonard Electric Company, Mount Vernon, N. Y., in 1935, and was named electrical design engineer in 1937. In 1942 he was placed in charge of the design section of the engineering department and in this position supervised development on electric motor control apparatus for the United States Navy. He is a member of Sigma Xi.

K. A. Auty (A '12, M '17) sales engineer, Commonwealth Edison Company, Chicago, Ill., has retired. Mr. Auty was born in England in 1878. After earning a second mate's certificate in the Royal Navy, he attended the Sorbonne and in 1899 was graduated from Victoria University. From 1899 to 1907 he was with the Brush Electrical Engineering Company, Ltd., Loughborough, England, first as draftsman and member of the technical staff; later as branch manager and engineer for the company's Lancashire, Cheshire, and Cumberland districts; and finally as company representative and erecting engineer in Japan. He joined the British Columbia Electric Railway Company, Ltd., Vancouver, Canada, as chief illuminating and power engineer in 1909. As sales engineer and isolated plant specialist he entered the employ of the Commonwealth Edison Company in 1915. In 1917 he received the Insull medal. Mr. Auty was AIEE vice-president for 1932–34, was one of the organizers of the AIEE Vancouver Section, and is a former officer of the Chicago Section. He assisted in the founding of the Midwest Power Engineering Conference and served as one of its officers for a number of years. An active member of the Western Society of Engineers, he has served on the Washington Award Commission. He is a member of the Association of Iron and Steel Engineers, and the Illuminating Engineering Society.

H. B. Hansteen (A '26, M '43) formerly assistant professor of electrical engineering, College of the City of New York, N. Y., has been appointed associate professor of electrical engineering, at Cornell University, Ithaca, N. Y. Professor Hansteen holds the degree of electrical engineer (1924) from Polytechnic Institute of Brooklyn, and the degrees of master of arts (1929) and doctor of philosophy (1942) from Columbia University. He commenced his teaching career as instructor in mathematics at the Polytechnic Institute of Brooklyn, N. Y., in 1926. In 1929 he became an instructor at Columbia University, New York, and in 1930 returned to Polytechnic Institute of Brooklyn. He had been a member of the faculty of the College of the City of New York since 1937. Professor Hansteen was associated with the construction of the cyclotrons at Columbia University from 1935 to 1940 and with research on uranium fission under Professor Enrico Fermi. He also taught courses on radar and ultrahigh frequencies techniques for the United States Navy during the war. He is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

W. W. Lewis (A '09, F '38) formerly transmission engineer, central station engineering division, General Electric Company, Schenectady, N. Y., has been appointed professor of electrical engineering at Union College, Schenectady, N. Y. Born in Denver, Colo., Doctor Lewis received the degrees of bachelor of science in 1907, electrical engineer in 1923, and honorary doctor of science in 1936 from the University of Colorado. He was awarded the master of science degree by Union College in 1923. After completing the company test course at Schenectady, N. Y., in 1909, Doctor Lewis engaged in transmission engineering at the company's Pittsfield,

G. S. Whitlow

D. E. Moat

C. C. Wilson

Tomlinson Fort

Mass., plant until 1916, in which year he was transferred to the power and mining engineering department in Schenectady. In 1920 he was transferred to the lighting engineering department and since 1922 has been engineer in the central station division. He was sent to Japan and China in 1922 and to France, Italy, Germany, Belgium, and England in 1929. He is a member of CIGRE, the International Conference on Large Electric High-Voltage Systems, and Tau Beta Pi.

K. B. Aldrich (A '45) formerly chief, transmission development unit, Bonneville Power Administration, Portland, Oreg., recently was appointed director of the Arizona Power Authority, Phoenix. Mr. Aldrich received the degree of bachelor of science in electrical engineering from the University of Washington in 1922 and has been consulting engineer with many firms in Portland, Oreg., and Tacoma, Wash. He was dean of the engineering department of the evening session of Tacoma City College from 1922 to 1926, instructor in Oregon Institute of Technology from 1926 to 1928, and dean of higher mathematics in Portland City College in 1930. He was special agent for the division of investigation of the Public Works Administration from 1933 to 1937 and consultant to the Oregon State Hydroelectric Commission, and from 1938 to 1941 was research analyst for the Bonneville Power Administration. He became chief of transmission development in 1941. He is a member of the Electrochemical Society, the National Society of Professional Engineers, and the Professional Engineers of Oregon.

C. D. Lindridge (A '19, M '19) engineer with Bell Telephone Laboratories, Inc., New York, N. Y., recently completed 40 years of service with the Bell System. Other members of the laboratories who have completed 35 years of service are: **A. B. Clark** (M '19, F '30) vice-president; **J. W. Gooderham** (A '22, M '29) telephone engineer; **S. I. Cory** (A '24, M '31) of the systems department; **P. A. Jeanne** (A '20, M '30) member of the technical staff of the protection development department; **O. H. Loynes** (A '20); **R. G. McCurdy** (A '16, F '34) director of electrical apparatus development; and **Erich von Nostitz** (A '22). Those recently completing 25 years of service are: **G. H. Downes** (M '36); **B. F. Lewis** (A '38) research engineer; **M. S. Mason** (M '31) of the personnel department; and **E. R. Taylor** (A '24) of the systems development department. **D. S. Bender** (A '37, M '42) field engineer, Washington, D. C., has completed 20 years with the Laboratories, and **H. A. Stone, Jr.** (A '43) of the application and development department, ten years.

G. J. Taylor (M '44) formerly supervisory engineer, lamp department, General Electric Company, New York, N. Y., has become president of the newly organized company, Taylor-Light, Inc., North Hackensack, N. J. The firm will operate as a division of the Appleman Glass Works. Mr. Taylor holds the degrees of bachelor of science and electrical engineer from Illinois Institute of Technology and the degree of master of science from Massachusetts Institute of Technology. He entered the lighting industry as sales and service engineer for the General Electric Vapor Lamp Company, Chicago, Ill., in 1926. From 1928 to 1933 he was with the G. & W. Electric Specialty Company, Chicago. In 1939 he entered the lamp department of the General Electric Company, Cleveland, Ohio, as head of the industrial section of the engineering division. In 1942 he was appointed supervisory engineer for the New York area. Mr. Taylor is a member of the Illuminating Engineering Society, the National Society of Professional Engineers, and the Electrical and Gas Association of New York.

Harner Selvidge (A '39, M '45) a member of the staff of the applied physics laboratory of the Johns Hopkins University, Baltimore, Md., since 1941, has been appointed director of special products development for the Bendix Aviation Corporation and as such will co-ordinate company work on guided missiles and pilotless aircraft. Doctor Selvidge holds the degrees of bachelor and master of science from Massachusetts Institute of Technology and the degree of doctor of science from Harvard University. He has been instructor at Harvard University, Cambridge, Mass., and associate professor at Kansas State College, Manhattan, from which he was given leave of absence to join the staff of Johns Hopkins. He has been consulting engineer for Taylor Tubes, Inc., Chicago, Ill., and director of research for the American Phenolic Corporation, Chicago, since 1938. At Johns Hopkins University he worked on the proximity fuse, rugged vacuum tubes, and guided missile projects.

J. C. Wright (A '12) member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., has retired. Mr. Wright was graduated from Cornell University with the degree of mechanical engineer in 1909 and entered the student course of the Western Electric Company at Hawthorne, Ill. The following year he was transferred to the physical laboratories in New York and remained with the organization when it became Bell Laboratories. His work has lain in the field of transmission apparatus development, and he supervised development work on incandescent lamps and switchboard signaling. During World War II, Mr. Wright worked on the development of wire used in electronic equipment for the Armed Forces.

Robert Steck (A '03, M '13) administrative assistant to the engineer, Winter Street works, General Electric Company, Fort Wayne, Ind., has retired. Mr. Steck, who was graduated from the University of Michigan in 1898, commenced his career as an engineer in the apparatus department of the Western Electric Company, Chicago, Ill., in 1899. He became head of that company's d-c motor and generator section in 1905, and in 1909 when that section of the company was purchased by the General Electric Company he continued with the latter in Schenectady, N. Y. He was transferred to the company's Fort Wayne works in 1916 as engineer in charge of electric transmission. He was made head of design engineering of the farm power and light division in 1918, and executive engineer of the refrigeration division at the Winter Street works in 1924. Since 1931 he has been administrative assistant to the engineer in charge.

J. A. Cortelli (A '45) formerly chief engineer of commercial engineering, Clark Controller Company, Cleveland, Ohio, has been appointed chief engineer of the company. Mr. Cortelli was graduated from the Case School of Applied Science with the degree of bachelor of science in electrical engineering in 1928. Since that time, except for the year 1933 in which he was test engineer for Waite and Bartlett X-Ray Company, Cleveland, he has been with the Clark Company. He was engineer in the test, drafting, and engineering departments and in 1934 was named commercial engineer. **P. M. Christensen** (A '38, M '44) formerly research and development engineer, has been appointed manager of the development engineering department. A 1933 graduate of Trinity College, Mr. Christensen previously was chief engineer of the Colt Patent Fire Arms Manufacturing Company, Hartford, Conn. He joined the Clark Company in 1944.

F. T. Bear (A '23, M '31) formerly assistant electrical engineer, Delaware Power and Light Company, Wilmington, has been made chief engineer of the engineering department. A 1922 graduate of Pennsylvania State College, Mr. Bear was employed first by the Philadelphia (Pa.) Suburban Gas and Electric Company which later was absorbed by the United Gas Improvement Company. In 1928 Mr. Bear joined the Delaware company, and since 1945 he has been in charge of planning and supervising engineering development. **E. R. Streed** (A '33) engineer with the company since 1932 has been appointed assistant chief engineer. He is a 1931 graduate of Drexel Institute. **William Corrigan** (A '45) formerly relief system operator, has been appointed supervisor of system operation.

J. W. Latham (M '27) formerly chief engineer, Chesapeake and Potomac Telephone Company, Baltimore, Md., has been appointed assistant to the general manager. A graduate of the University of Virginia, Mr. Latham commenced his career with the Bell System in the engineering and installation departments of the Western Electric Company, Chicago, Ill., in 1906. He was assigned to the Southern Bell Tele-

phone and Telegraph Company, Atlanta, Ga., in 1909, as engineer inspector and was made traffic supervisor at Charlotte, N. C., in 1910, and at Savannah, Ga., in 1912. He returned to Atlanta as traffic equipment engineer in 1913. Transferred to the Chesapeake and Potomac company in 1920, he was named facilities engineer in 1922 and was appointed chief engineer in 1929.

J. M. Wilson (A '23, M '33) formerly division manager, Virginia Electric and Power Company, Clifton Forge, Va., has been elected vice-president in charge of the western division of the company. Mr. Wilson's first utility position was that of superintendent for the Savannah (Ga.) Lighting Company in 1912, and in 1914 he joined the Virginia Western Power Company as local superintendent. During World War I he served with the United States Engineers and afterwards returned to the Virginia Western company as superintendent of its Hinton, W. Va., district. In 1924 he was made merchandising manager. He joined the Virginia Public Service Company, predecessor of the Electric and Power company, in 1928 as district manager.

Myron Zucker (A '27, M '36) engineer with Mackworth G. Rees, Inc., Detroit, Mich., since 1944, has been appointed a vice-president of the company. Born in New York, N. Y., in 1905, Mr. Zucker received the degree of electrical engineer from Cornell University in 1925 and the degree of master of science from Union University in 1927. He was associated with the General Electric Company, Schenectady, N. Y., from 1925 to 1929, working on testing, thyratron application development, and central station engineering. In 1929 he entered the engineering division of the Detroit Edison Company. He is a member of the Engineering Society of Detroit.

Bertram Wellman (A '26) formerly development engineer, Photoswitch, Inc., Cambridge, Mass., is president of the Electrodyne Company, Boston, Mass., a newly formed corporation. Mr. Wellman, who received the bachelor of science degree in 1924 from Harvard University and the master of science degree in 1937 from Massachusetts Institute of Technology, was associated with the research laboratory of the General Electric Company, Schenectady, N. Y., until 1932. He became research associate in psychology at the University of Rochester in 1937 and assistant director of the research laboratory of sensory psychology and physiology at Tufts College, Medford, Mass., in 1938.

W. J. Ellenberger (A '31, M '38) recently released from duty with the Signal Corps as a lieutenant colonel, has been appointed plant superintendent at the National Bureau of Standards, Washington, D. C. From 1942 until his release from active duty, Mr. Ellenberger served in the Signal Corps first as executive officer, Resources Branch, Office of the Chief Signal Officer; later as chief of the Signal Section, International Division, Army Service Forces; and most recently as assistant executive, United States Staff, London Munitions Assignment Board. He was awarded the Army Commendation Ribbon and the Order of the British Empire for his services in connection with military lend-lease.

H. W. Biskeborn (M '39) formerly chief engineer, Phillips Electrical Works, Ltd., Brockville, Ontario, Canada, recently joined the Canadian Comstock Company, Montreal, Quebec, Canada. Born in Hanover, Germany, in 1898, Mr. Biskeborn was graduated from the Polytechnic School of Engineering in 1917. From 1919 to 1938 he was associated with various English firms: the Hart Accumulator Company, Ltd., London; the British Electric Transformer Company, Ltd., Middlesex; the Hackbridge Electric Construction Company, Ltd. Waltham-on-Thames; and Crompton Parkinson, Ltd., Chelmsford. In 1938 he returned to Canada, where in 1930 he had organized the Hackbridge Transformer Company of Canada, as electrical and development engineer for the Phillips Works.

P. E. Shaad (A '34, M '46) formerly plant engineer, Spreckels Sugar Company, Woodland, Calif., has been appointed chief electrical engineer of the Sacramento (Calif.) Municipal Utility District. The electric distribution system for which Mr. Shaad is responsible is being purchased from the Pacific Gas and Electric Company effective December 31, 1946. Mr. Shaad was graduated from the University of Kansas with the degree of electrical engineer for 1933. From 1933 to 1940 he was associated with the General Electric Company, Schenectady, N. Y., and San Francisco, Calif., engaging in steam turbine testing, industrial control design, commercial engineering, and field engineering. He was sent to Hawaii to survey sugar plantations in 1938 and in 1940 became electrical engineer for the Hawaiian Electric Company, Ltd., Honolulu. He returned to California in 1944 to become plant engineer for the Spreckels company. Mr. Shaad is a member of Tau Beta Pi, Sigma Tau, and the National Society of Professional Engineers.

Alexander Maxwell (F '37) director of engineering, Edison Electric Institute, New York, N. Y., has retired. Mr. Maxwell was born in New York in 1878. From 1895 to 1924 he was associated with the New York Edison Company and its predecessors as assistant superintendent of operation. In 1924 he joined the staff of the National Electric Light Association, and, when that organization was dissolved in 1933, he became director of engineering for the Edison Electric Institute. Mr. Maxwell served in the Field Artillery in World War I and was discharged from service as a lieutenant colonel. He has served as chairman of the AIEE committees on Standards and domestic and commercial applications and as chairman of the board of examiners.

W. A. Lewis, Jr. (A '27, F '45) research professor of electrical engineering at Illinois Institute of Technology and consultant to the institute's Armour Research Foundation has been appointed dean of the institute's graduate school. Doctor Lewis received the degrees of bachelor of science in 1926, master of science in 1927, and doctor of philosophy in 1929 from the California Institute of Technology. Until 1939 he was central station engineer with the Westinghouse Electric Corporation, East Pittsburgh, Pa., and that year was appointed director of the school of engineering at Cornell University, Ithaca, N. Y. He joined the faculty of the Illinois Institute of Technology in 1944.

Frank Noakes (A '41) formerly assistant research engineer with the Hydro-Electric Commission of Ontario, Toronto, Canada, has been appointed associate professor of electrical engineering at the University of British Columbia, Vancouver. Doctor Noakes holds the degree of bachelor of science (1937) from the University of Alberta and the degrees of master of science and doctor of philosophy from Iowa State College. He was a graduate teaching and research assistant at Iowa State College, Ames, from 1937 to 1940 and a lecturer at the University of Toronto from 1940 to 1943. Since 1943 he has been with the Hydro-Electric Commission.

E. J. Butler (A '30) formerly electrical engineer, Western Electric Company, Inc., Kearny, N. J., has joined the faculty of the Thayer School of Engineering, Dartmouth College, Hanover, N. H., as assistant professor of engineering and management. Professor Butler was graduated from Rutgers University with the degree of bachelor of science in 1924 and after a brief association with the Westinghouse Electric Corporation, East Pittsburgh, Pa., became assistant power engineer with the New York and Queens Electric Light and Power Company, Long Island City. He was titled commercial engineer in 1929 and manager of the commercial engineering bureau in 1935. During the war Mr. Butler was with the Western Electric Company and the Raytheon Company on special communications assignments.

J. K. Nunan (A '39) West Coast manager of professional motion picture sales, Ansco division, General Aniline and Film Corporation, Los Angeles, Calif., recently was awarded the Navy Medal for Merit. The award was in recognition of his wartime services as assistant resident director of the New London (Conn.) Laboratory and director of the Pearl Harbor division of the Columbia University Division of War Re-

search. Mr. Nunan is a graduate of the University of Southern California, and a former professor at the University of Southern California and the California Institute of Technology.

O. E. Buckley (M '19, F '29) president, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed a member of a special Advisory Committee on Ordnance Research and Development formed by the Army Ordnance Association. Doctor Buckley also has been awarded the Medal for Merit. The citation accompanying the award read: "He displayed great foresight by expediting development . . . even before its military value had become apparent, and his leadership was reflected in the highly effective collaboration of scientists and technicians who overcame extremely complex problems in the development of new electronic techniques essential to success."

G. W. Douglass (M '32) formerly engineer of exchange plant extension, New Jersey Bell Telephone Company, Newark, has been appointed chief engineer of the company. Mr. Douglass was graduated from the Polytechnic Institute of Brooklyn in 1909 and in 1910 became an engineering assistant with the New York Telephone, New York. In 1925 he was made engineer of exchange plant extension for the New Jersey area of the company and in 1927 was transferred to the New Jersey company in that capacity.

W. B. Beals (A '09, M '27) staff engineer, Chesapeake and Potomac Telephone Company, Washington, D. C., has retired. Born in Norwich, N. Y., in 1881, Mr. Beals earned the degree of mechanical engineer from Cornell University in 1902. He joined the Baltimore division of the Chesapeake and Potomac Telephone Company in 1904. In 1912 he was transferred to Washington, and in 1913 was named outside plant engineer. He became transmission and protective engineer in 1928 and staff engineer in 1929.

C. M. Fulk (A '16) electrical engineer, central station engineering division, apparatus department, General Electric Company, Schenectady, N. Y., has retired. Born in 1881, Mr. Fulk was graduated from Purdue University in 1907 with the degree of bachelor of science in electrical engineering. Immediately after graduation he entered the test course of the General Electric Company and from 1917 to 1922 was assigned to d-c design and field engineering in the New York, N. Y., office of the company. Since 1922 he has been engaged in application engineering with the central station division in Schenectady.

Frank Breckenridge (M '43) formerly chief engineer, home appliance division, Federal Telephone and Radio Corporation, Newark, N. J., is now vice-president and chief engineer of the Automatic Washer Company, Newton, Iowa. Mr. Breckenridge previously had been associated with the Automatic Washer Company from 1929 to 1932. Since that time he has been associated variously with the One Minute Manufacturing Company, Newton; the Conlon Corporation, Chicago, Ill.; and the Westinghouse Electric and Manufacturing Company, Mansfield, Ohio.

B. A. Fisher (M '45) formerly in charge of graduate work in electronics and communications at Oklahoma Agricultural and Mechanical College, Stillwater, has been appointed professor of electrical engineering at the University of Denver, Colo. Professor Fisher received the bachelor of science degree from the University of Missouri in 1924 and the master of science degree from Harvard University in 1937. Previously associated with the University of Nevada and South Dakota State College, Professor Fisher recently served in the United States Naval Reserve as lieutenant commander and instructor in electrical engineering at the United States Naval Academy, Annapolis, Md.

E. S. Lee (A '20, F '30) engineer in charge of the General Electric Laboratories, Schenectady, N. Y., recently made a one-month tour of electrical manufacturing companies in England and France to discuss developments in engineering and science. While in France, Mr. Lee attended the Paris meeting of the International Technical Congress and from September 22 to 29 acted as official AIEE delegate to the sixth Industrial Congress for Applied Mechanics in Paris.

G. F. Crowell (A '20, F '42) formerly chief engineer, Wisconsin Telephone Company, Milwaukee, has been elected a vice-president of the company. After a brief period with the Yarmouth (Nova Scotia, Canada) Telephone Company, Mr. Crowell entered the plant department of the Wisconsin Telephone Company in 1906. He was assigned to central office equipment engineering in 1912 and named transmission and protection engineer in 1917. He has been chief engineer of the company since 1928.

C. H. Giroux (M '25, F '44) special assistant to the Chief of Engineers, Washington, D. C., recently was awarded the Exceptional Civilian Service Medal for his services during World War II. During the war, Mr. Giroux, who has been with the War Department since 1923, acted as consultant in connection with power supply to war industries and assisted in the development and utilization of power equipment for the Armed Forces. He also served as consultant to the Manhattan District.

W. L. Rubel (M '39) formerly captain, United States Naval Reserve, on the staff of the Production Officer, New York Naval Shipyard, has joined the firm of Guy B. Panero, New York, N. Y., as an associate in charge of the industrial and power division. Mr. Rubel previously was associated with Sanderson and Porter, New York, and was chief engineer of the Memco Engineering and Manufacturing Company, Long Island City, N. Y.

W. R. Whitney (A '01) vice-president in charge of research, General Electric Company, Schenectady, N. Y., recently received the first Industrial Research Institute Medal "for his outstanding contributions to the field of industrial research as a distinguished scientist, a pioneer of industrial research, and a leader and molder of men."

W. S. Hill (A '25, M '30) formerly assistant district engineer, General Electric Company, Buffalo, N. Y., has been appointed to the recently created post of manager of engineering of the Locke Insulator Corporation, Baltimore, Md. All engineering activities consisting of ceramic, design and development, and requisition engineering have been combined into one engineering department which will be managed by Mr. Hill. Mr. Hill was graduated from the University of Nevada.

G. D. McCann (A '38, M '44) formerly transmission engineer, industry engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been appointed associate professor of electrical engineering at California Institute of Technology, Pasadena. Further biographical details on Doctor McCann can be found in the July issue of *Electrical Engineering*, page 355.

M. J. Smith (A '38) formerly instructor at Rice Institute, Houston, Tex., has been appointed assistant professor of electrical engineering at the University of Colorado, Denver. Professor Smith was graduated from Rice Institute in 1931 and was instructor at the University of Colorado from 1941 to 1943.

T. M. Odarenko (M '42) products line manager, Federal Telephone and Radio Corporation, Clifton, N. J., has been assigned to direct an investigation of special developments in the German communications industry of interest to American manufacturers. His report will be made available through the Office of the Publication Board, United States Department of Commerce.

J. B. Moore (M '41) formerly of the plant design engineering department, RCA Communications, Inc., New York, N. Y., was assigned to the Far East in May to assist General MacArthur's Civil Communications Section. Mr. Moore has been with RCA since 1922, when he entered the company's employ as a receiving engineer.

J. W. McRae (A '37) electrovisual engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed director of radio projects and television research for that organization. Doctor

McRae became affiliated with Bell Laboratories at Deal, N. J., in 1937. During the war he served as a colonel in the Signal Corps.

A. W. K. Billings (A '07, F '13) president, Brazilian Traction, Light and Power Company, Ltd., Rio de Janeiro, has been awarded the National Order of the Southern Cross, highest civilian decoration of the Government of Brazil in recognition of his development of hydroelectric resources in the Sao Paulo–Rio de Janeiro area.

E. F. Pearson (M '20, F '37) formerly assistant to the vice-president and general manager, Northwestern Electric Company, Portland, Oreg., has been appointed assistant general manager with offices in Vancouver, Wash. Mr. Pearson has been with the Northwestern company for 34 years, and he has been assistant to the general manager since 1935.

Elliot Ginochio (A '45) formerly industrial power engineer, Pacific Gas and Electric Company, Sacramento, Calif., has been appointed sales manager of the Shasta division of that company. Mr. Ginochio has been associated with the Pacific Gas and Electric Company since 1929.

H. E. Ellis (A '31, M '42) formerly electrical design engineer, Westinghouse Electric Corporation, Lima, Ohio, has been appointed chief engineer of Electro Machines, Inc., Cedarburg, Wis. Mr. Ellis had been with the Westinghouse company for 17 years.

Carl Whitmore (A '18) president of the New York Telephone Company, N. Y., has received a War Department Certificate of Appreciation in recognition of his services in "providing communications facilities to Army installations. . . and for expert assistance in the establishment of aircraft warning systems."

W. T. Johnson (A '39) formerly assistant to the general superintendent, California Electric Power Company, Riverside, has been appointed general superintendent. Mr. Johnson joined the company in 1924 as superintendent at Yuma, Ariz., and district superintendent of operations in the Imperial Valley, Calif.

V. G. Muznay (A '38) formerly assistant engineer, Puget Sound district, Bonneville Power Administration, Seattle, Wash., has been transferred to the Portland engineering division. **J. V. Lamson** (A '29, M '42) formerly district engineer for the Administration at Portland has replaced Mr. Muznay.

Harvey Fletcher (M '23, F '30) director of physical research, Bell Telephone Laboratories, Inc., New York, N. Y., has been made a member of the committee on John J. Carty Fund of the National Academy of Sciences for a term of five years.

J. F. Gogins (A '40) formerly general manager of the Spokane, Wash., office of the General Electric Company has been made assistant district sales manager for the entire Pacific Northwest and Alaska. His headquarters will be in Portland, Oreg.

C. B. McCartney (A '43) superintendent of transmission and distribution, Florida Power Corporation, St. Petersburg, has resigned to become a consulting engineer. He was graduated from the Milwaukee School of Engineering in 1924.

E. I. Pollard (A '35, M '45) has been appointed engineering manager of the Elliott Company's Ridgway (Pa.) division. Mr. Pollard, who joined the company earlier this year, previously was associated with the Westinghouse Electric Corporation, East Pittsburgh, Pa.

T. C. Clarke (A '35, M '42) district manager, Northern Electric Company, Ltd., Vancouver, British Columbia, Canada, has been appointed a director of the Langley Manufacturing Company, Ltd., Vancouver, and the Langley Electrical Company, Ltd., Calgary.

J. H. Polhemus (M '40) president, Portland (Oreg.) General Electric Company, was elected president of the Northwest Electric Light and Power Association at the annual meeting held recently in Seattle, Wash.

R. P. Glover (M '45) consulting engineer, Oak Park, Ill., has been appointed technical representative in the Chicago area by Technology Instrument Corporation, Waltham, Mass.

W. L. Hetherington (A '40) formerly engineer, Steel Company of Canada, Montreal, Quebec, is now with the Packard Electric Company, St. Catharines, Ontario, Canada.

J. W. Lingary (M '32) superintendent of electric plant, Lynn (Mass.) Gas and Electric Company, has been elected chairman of the New England System Operators Club.

E. C. Crittenden (A '19, F '44) associate director, National Bureau of Standards, Washington, D. C., has been elected a member of the International Committee on Weights and Measures. Doctor Crittenden recently was awarded the honorary degree of doctor of science by the Case School of Applied Science.

G. M. Heinze (A '37) formerly assistant engineer, electrical engineering department, New York, New Haven, and Hartford Railroad, New Haven, Conn., has been named electrical supervisor.

L. F. Greve (M '38) electrolysis engineer, Commonwealth Edison Company, Chicago, Ill., has been elected chairman of the newly formed North Central regional division of the National Association of Corrosion Engineers.

H. B. Waters (A '04) formerly president, Telluride Power Company, Salt Lake City, Utah, has been elected chairman of the board for the company.

W. V. Kahler (M '39) vice-president in charge of operation, Illinois Bell Telephone Company, Chicago, has been elected chairman of the Washington Award Commission for 1946–47.

M. J. McHenry (A '11, M '20) director of promotion, Hydro-Electric Power Commission of Ontario, Toronto, Canada, has been elected president of the Electric Service League of Ontario.

E. O. Slaybaugh (M '43) formerly assistant division superintendent, Consumers Power Company, Battle Creek, Mich., has been appointed division superintendent.

P. Dunsheath (M '22) director and chief engineer, W. T. Henley's Telegraph Works Company, Ltd., London, England, has been elected honorary secretary of the International Electrotechnical Commission.

OBITUARY • • • •

Frank Ambler Pattison (A '91, M '91, F '13) consulting engineer and retired member of the firm, Pattison Brothers, New York, N. Y., died September 18, 1946. Mr. Pattison, who was born in New York, December 10, 1867, was graduated from Rutgers College in 1887 with the degree of bachelor of arts. He received the degree of master of arts in 1890. Before entering college he spent some time experimenting at the Edison works in Menlo Park, N. J. After brief employment with the Edison Electric Company of New York and the Edison Electric Illuminating Company of New Orleans, La., he opened his own consulting office in New York. In 1891 he and his brother founded the firm of Pattison Brothers which was continued until Mr. Pattison retired in 1937. The firm planned the electrical, mechanical, heating, and ventilating systems for many well-known buildings in New York, among them museums, hotels, the stock exchange, banks, insurance companies, newspapers, and private residences. The firm also worked on the stock exchange in Montreal, Quebec, Canada, and insurance company buildings in Boston, Cleveland, Newark, Providence, and Springfield, Mass. Mr. Pattison had served on the AIEE committee on safety codes. In 1916 he was a delegate to the Progressive National Convention and in 1924 was a member of the committee which supported Senator Robert M. LaFollette, Sr., for President. He was a member of the American Society of Mechanical Engineers, and the Engineers Club of New York.

James Enon Macdonald (A '03, M '13) retired secretary, Joint Pole Committee, Los Angeles, Calif., died August 8, 1946. Mr. Macdonald, who was born in New Glasgow, Nova Scotia, Canada, October 27, 1874, was graduated from McGill University with the degree of bachelor of science in 1897. After graduation he was draftsman with Brown and Sharpe Manufacturing Company, Providence, R. I., in 1897 and 1898 and with the William Sel-

lers Company, Philadelphia, Pa., in 1899. He went to Los Angeles in 1900 as draftsman for the Baker Iron Works. Entering the employ of the Pacific Electric Railway Company, Los Angeles, in 1902, he became successively electrician, foreman, engineer in charge of electrical testing, and assistant electrical engineer. In 1907 he was appointed secretary of the Joint Pole Committee formed in Los Angeles by four railways and three electric companies to bring about the common use of poles on a joint ownership basis. At the time of Mr. Macdonald's retirement in 1940, the committee's membership had grown to 28 utilities whose scope of operation covers most of Southern California and part of the San Joaquin Valley. Mr. Macdonald served as an AIEE vice-president for 1923–25 and was one of the group which organized the Los Angeles Section of the Institute. He had served on the AIEE committees on Sections, membership, and meeting and papers. He was president of the Los Angeles Engineering Council for 1934–35.

Louis Frederick Blume (A '09, M '34, F '39) retired assistant engineer, transformer engineering department, General Electric Company, Pittsfield, Mass., died August 14, 1946. Born in Philadelphia, Pa., November 14, 1882, Mr. Blume received the degree of electrical engineer from Lehigh University in 1905 and the degree of master of arts from Cornell University in 1909. He was instructor in the Lowell (Mass.) Textile High School in 1906 and 1907 and at Cornell University from 1907 to 1909. He entered the employ of the General Electric Company at Pittsfield in 1909 as designer in the transformer engineering department and in 1926 was named assistant engineer. He received the Coffin Award in 1924 for development of a method of regulating transformer voltage and again in 1929 for the development of nonresonating transformers. Mr. Blume was the author of a number of technical papers and was the editor and coauthor of "Transformer Engineering." He was granted more than 20 patents. He served on the AIEE committee on Standards from 1915 to 1922.

William F. Filer (M '26) switching development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., died June 24, 1946. He was born November 8, 1888, in Hilton, N. Y., and attended Pratt Institute. Mr. Filer entered the employ of the Western Electric Company in 1906 and was assigned to installation work in the West and Southwest. In 1911 he was assigned to the circuit laboratory in New York and in 1915 was made supervisor of the development of manual telephone circuits. During World War I he was in charge of a group on Army and Navy work. He was made supervisor of development for both manual and automatic telephone systems in 1922. After 1925 he continued with this work with Bell Telephone Laboratories. During the recent war he supervised the circuit development for the Army's air warning network and also did much work for the Civil Aeronautics Administration.

William Lester Dively (A '27) district representative, Century Electric Company, Buffalo, N. Y., died recently. Mr. Dively was born October 6, 1900, in Claysburg, Pa., and was graduated from the University of Pittsburgh with the degree of bachelor of science in electrical engineering. He joined the Century company in St. Louis, Mo., in 1925 and was transferred to Philadelphia the following year. He became company representative at Buffalo in 1940.

MEMBERSHIP ••

Recommended for Transfer

The board of examiners, at its meeting of September 19, 1946, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Bibber, H. W., chairman, div. of engg., and prof., elec. engg., Union College, Schenectady, N. Y.
Carpenter, J. W., pres. & general mgr., Texas Pr. & Lt. Co., Dallas, Tex.
Daly, C. J., trans. & outside plant engr., Southern New England Tel. Co., New Haven, Conn.
Demuth, O. A., chief, systems engg. staff, Bonneville Pr. Adm., Portland, Oreg.
Dillard, E. W., elec. engr., New England Pr. Service Co., Boston, Mass.
Hamilton, R. F., elec. engr., P-8, U. S. Civil Service, Washington, D. C.
Jump, G. H., dist. engr., General Elec. Co., Boston, Mass.
Love, N. R., chief engr., Denver Tramway Corp., Denver, Colo.
Lowenberg, M. J., sr. elec. engr., Stone & Webster Engg. Corp., Boston, Mass.
Pettee, A. D., chief engr., General Cable Corp., New York, N. Y.
Polhemus, J. H., pres., Portland General Elec. Co., Portland, Oreg.
Port, E. G., technical director, radio div., Federal Tel. & Radio Corp., Newark, N. J.
Stafford, R. T., mgr., transformer sec., Allis-Chalmers Mfg. Co., Pittsburgh, Pa.
Stewart, H. R., protection engr., New England Pr. Service Co., Boston, Mass.

14 to grade of Fellow

To Grade of Member

Alfers, J. B., elec. engr., Navy Dept., Bureau of Ships, Washington, D. C.
Anderson, R. E., distribution engr., Southwestern Gas & Elec. Co., Marshall, Tex.
Asbury, C. E., elec. engr., Commonwealth & Southern Corp., Detroit, Mich.
Bailey, A. D., ass't prof., elec. engg., Univ. of Illinois, Urbana, Ill.
Bauer, J. L., application engr., ind. engr. divs., General Elec. Co., Schenectady, N. Y.
Beale, R. L., div. engr., Texas Elec. Service Co., Big Spring, Tex.
Becker, H. W., electronics instructor, Mare Island Fire Control School, Mare Island, Calif.
Bourne, R. F., engg. representative, Colorado Fuel & Iron Corp., Denver, Colo.
Bowman, J. F., elec. engr., Fisk tire plant, U. S. Rubber Co., Chicopee Falls, Mass.
Brannan, A. I., chief elec. engg., Mene Grande Oil Co., western div., Maracaibo, Venezuela, S. A.
Bruns, S. W., illuminating & designing engr., Rambusch Decorating Co., New York, N. Y.
Burrell, K. H., ind. control specialist, General Elec. Co., Cleveland, Ohio.
Castonguay, W. R., service engr., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Clatterbaugh, F. C., instructor, Iowa State College, elec. engg. dept., Ames, Iowa.
Cunningham, J. C., Jr., elec. aviation application engr., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Davenport, H. H., engineer, Southwestern Bell Tel. Co., Dallas, Tex.
del Busto, A. F., ass't supt., transm. & dist., Mexican Lt. & Pr. Co., Ltd., Mexico, D. F., Mexico.
Dillingham, H. C., prof. of elec. engg., A & M College of Texas, College Station, Tex.
Duphorne, H. M., inventory & costs engr., Southwestern Bell Tel. Co., St. Louis, Mo.
Edwards, R. F., design engineer, Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Eichhorn, C. W., design engr., Raytheon Mfg. Co., Waltham, Mass.
Fain, J., control engineer, Public Service Elec. & Gas Co., Newark, N. J.
Fenlon, D. R., sr. engr., Turf Development Board, Dublin, Ireland.
Fister, E. J., elec. engr., Signal Corps engg. labs., Evans Signal Lab., Belmar, N. J.
Fouracre, V. W. M., manager, Barvic Engineering, Ltd., Vancouver, British Columbia, Canada.
Fowler, W. K., manager for Far East, apparatus div., International General Elec. Co., Schenectady, N. Y.
Franklin, J. S., engr., lighting div., General Elec. Co., West Lynn, Mass.
Friel, A. C., elec. engr., Dow Chemical Co., Midland, Mich.
George, R. H., research prof., elec. engg. div., Purdue Univ., Lafayette, Ind.
Goodheart, C. F., ordnance engr., Naval Gun Factory, Naval Ordnance Lab., Washington, D. C.
Gorman, W. J., div. working practices supv., American Tel. & Tel. Co., Philadelphia, Pa.
Hale, P. W., ass't engr., Consolidated Edison Co. of New York, Inc., New York, N. Y.
Hall, W. M., radio engineer, Raytheon Mfg. Co., Waltham, Mass.
Higgins, T. J., associate prof., elec. engg., Illinois Institute of Technology, Chicago, Ill.
Hoyt, T. C., elec. engr., Ebasco Services, Inc., New York, N. Y.
Hutloff, E. W., elec. designer & div. head, Public Service Elec. & Gas Co., Newark, N. J.
Joyner, K. O., elec. engr., National Advisory Comm. for Aeronautics, Langley Field, Va.
Liensch, J. P., development engr., Foxboro Co., Foxboro, Mass.
Loeffler, H. F., co-ordination engr., Wisconsin Tel. Co., Milwaukee, Wis.
Louret, H. A., sr. engr., engg. dept., Commonwealth Edison Co., Chicago, Ill.
Malone, Jr., C., elec. engr., Hazel-Atlas Glass Co., Wheeling, W. Va.
Michaels, H. J., design engr., Allis-Chalmers Mfg. Co., West Allis, Wis.
Michel, M., elec. engr., Aluminum Co. of America, Pittsburgh, Pa.
Miller, G. W., chief engr., Rochester Tel. Corp., Rochester, N. Y.
Miller, J. B., retired, 200 Masonic Bldg., Oregon City, Oreg.
Monteith, C. D., elec. engr., c/o National Park Service, Chicago, Ill.
Murphy, L. K., district engr., Westinghouse Elec. Corp., New York, N. Y.
Murphy, H. E., engr., General Electric Co., New York, N. Y.
Nelson, N. H., project mgr., G. B. Conner's & Co., Hollywood, Calif.
Nicholson, A. J., elec. engr., Kansas City Pr. & Lt. Co., Kansas City, Mo.
Raine, R. W., elec. designer, partner, Edward D. de Luca & Associates, Sp., Jacksonville, Fla.
Rettig, V. G., elec. planning engr., Cincinnati Gas & Elec. Co., Cincinnati, Ohio.
Roldan G, D., technical director, Industrias Unidas, S. A., Mexico, D. F., Mexico.
Rollins, C. A., ass't engr., Headman, Ferguson & Carollo, Phoenix, Ariz.
Rousult, C. L., prof. coms. engr., 704 Oak St., Syracuse, N. Y.
Schuster, E. F., ass't elec. engr., Underwriters' Laboratories, Inc., New York, N. Y.
Seltried, A. G., chief elec. engr., machine develop. dept., B. F. Goodrich Co., Akron, Ohio.
Seitz, R. M., elec. engr., Eastman Kodak Co., Rochester, N. Y.
Shallenberger, J. W., consulting elec. engr., 886 Main St., Bridgeport, Conn.
Shaw, Jr., M. R., research engr., physical lab., Corning Glass Works, Corning, N. Y.
Smith, Jr., H. M., application engr., Westinghouse Elec. International Co., New York, N. Y.
Stauffer, J. L., division engr., lines & stations, Pa. Pr. & Lt. Co., Lancaster, Pa.
Summers, S. D., elec. engr., staff consultant, aircraft electrical div., Naval Research Lab., Washington, D. C.
Taragin, S., elec. engr., Aberdeen Proving Grounds, Md.
Taylor, R. H., ass't engr., Narragansett Elec. Co., Providence, R. I.
Turner, Jr., R. C., commander, U. S. Naval Reserve, U. S. Naval Academy, Annapolis, Md.
Wainwright, R. M., research engr., Montana-Dakota Utilities Co., Glendive, Mont.
Westin, L. J., power plant engr., Day & Simmerman, Inc., Philadelphia, Pa.
Williams, H. E., vice-pres., Knox Porcelain Corp., Knoxville, Tenn.
Williams, S. B., research engr., Mass. Inst. of Tech., Cambridge, Mass.
Williges, A., engr., Hamilton & Williges, Oakland, Calif.

Wilson, N. E., Westinghouse fellow, Illinois Inst., of Tech., Chicago, Ill.
Witty, B. G., office & field engr., Allis-Chalmers Mfg. Co., Chicago, Ill.
Worcester, W. G., engr., General Elec. Co., Schenectady, N. Y.

74 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before November 21, 1946, or January 21, 1947, if the applicant resides outside of the United States or Canada.

To Grade of Member

Batnold, H. A., General Elec. Co., New York, N. Y.
Bird, G. T., University of Houston, Houston, Tex.
Blagg, S. M., Lt. Col., Royal Engineers, British Army, Sialkot, Punjab, India.
Blankenship, N., General Elec. Co., Dallas, Tex.
Boone, J. J., American Tel. & Tel. Co., Philadelphia, Pa.
Brownlee, A. L., Wico Elec. Co., W. Springfield, Mass.
Buttolph, M. D., Army Transportation Corps Board, Brooklyn, N. Y.
Campbell, D. L., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Clark, E. W., General Elec. Co., West Lynn, Mass.
Daniel, C. E., 325 N. Charles St., Baltimore, Md.
DeBaugh, R., U. S. Naval Shipyard Terminal Island, San Pedro, Calif.
DeWalt, K. C., General Elec. Co., Schenectady, N. Y.
Doll, H. F., Victor Elec. Products, Inc., Cincinnati, Ohio.
Erikson, B. W., General Elec. Co., Schenectady, N. Y.
Fleming, T. M., Kentucky Utilities Co., Lexington, Ky.
Garber, L. H., American Tel. & Tel. Co., Chicago, Ill.
Gostyn, E., F. W. Sickles Co., Chicopee, Mass.
Henderson, S. F., Westinghouse Elec. Corp., Buffalo, N. Y.
Hughes, M. R., Ulteig Engg. Co., Fargo, N. D.
Jackson, G. C. R., Major, Canadian Vocation Training Electrical School, Vancouver, B. C., Canada.
Kucera, C. F., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Longenecker, D. M., General Elec. Co., West Lynn, Mass.
Lowe, J. T., Bell Tel. Labs., Inc., New York, N. Y.
McKenna, A. T., North Wales Power Co., Ltd., Wrexham, North Wales, Great Britain.
McNutt, J., James Lees & Sons Co., Bridgeport, Pa.
Mincho, C. H., Harrisburg Steel Corp., Harrisburg, Pa.
Morales S., E., Agent-Holophane Co., Inc. of N. Y., Mexico, D. F., Mexico.
Myers, F. H. E., The British Thomson-Houston Co., Ltd., Rugby, England.
Paden, T. L., Pennsylvania Power Co., New Castle, Pa.
Roy, L., Quebec Hydro-Elec. Comm., Montreal, Que., Canada.
Slattery, J., Signal Corps Engg. Labs., Bradley Beach, N. J.
Stevens, H. B., Westinghouse Elec. Corp., Panama, R. P.
Warner, N. A., N. Y. Tel. Co., New York, N. Y.

33 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Blumenauer, C. E., U. S. Rubber Co., Chicopee Falls, Mass.
Campbell, H. E., General Elec. Co., Schenectady, N. Y.
Cohrs, W. C., Eastman Kodak Co., Rochester, N. Y.
Folsom, E. E., Jr., General Elec. Co., Bridgeport, Conn.
Hartshorn, J. A., New England Gas & Elec. Association, Cambridge, Mass.
Frybyla, J. J., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Rutecki, J. E., 84 Sassamon Ave., Milton, Mass.
Smet, J. E., Allis-Chalmers Mfg. Co., Boston, Mass.

2. Middle Eastern

Beasley, B. T., U. S. Naval Ordnance Plant, South Charleston, W. Va.
Beller, A. C., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Bliss, A. E., Hartford Steam Boiler Insp. & Ins. Co., Cleveland, Ohio.
Boenning, C. R., The Johns Hopkins University, Baltimore, Md.
Deveney, A. B., Philadelphia Elec. Co., Philadelphia, Pa.
Eidson, L. U., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Femiano, D., Potomac Elec. Power Co., Washington, D. C.
Graber, R. P., Koppers Co., Inc., Newport, Del.
Grubb, R. K., Delaware Pr. & Lt. Co., Wilmington, Del.
Higgins, C. F., Nat'l. Advisory Comm. of Aeronautics, Cleveland, Ohio.
Hutchins, J. L., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Johnson, E. F., Clark Controller Co., Cleveland, Ohio.
Kisel, J. (re-election), Rural Electrification Administration, Washington, D. C.
Lee, W. A., Jr., Westinghouse Elec., East Pittsburgh, Pa.
Lusk, R. J., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Magee, W. P., Philadelphia Elec. Co., Philadelphia, Pa.
Mandris, T. L., David Taylor Model Basin, Washington, D. C.
Michels, W. G., Division of Lt. & Pr., Cleveland, Ohio.
Puette, R. L., The Clark Controller Co., Cleveland, Ohio.
Scholze, R. T., Westinghouse Elec. Corp., Cleveland, Ohio.
Stewart, C. F., Carbide & Carbon Chemicals Corp., South Charleston, W. Va.
Szabo, L. J., Leece-Neville Co., Cleveland, Ohio.
Tarn, L. W., Bell Tel. Co. of Pa., Pittsburgh, Pa.
Wellens, H. E., Otis Elevator Co., Philadelphia, Pa.
Yeide, H. E., Potomac Elec. Pr. Co., Washington, D. C.

3. New York City

Adams, W. F., N. Y. State Public Service Comm., New York, N. Y.
Bruhn, N., N. Y. City Bd. of Transportation, New York, N. Y.
Chan, W. W., Sperry Gyroscope Co., Inc., Garden City, N. Y.
Di Sesa, L. E., Otis Elevator Co., Yonkers, N. Y.
Faulkner, F. K., Public Service Elec. & Gas Co., Newark, N. J.
Ferber, A. H., N. J. Bell Tel. Co., Morristown, N. J.
Ferrier, L. H., Consolidated Edison Co. of N. Y., Inc., New York, N. Y.
Heymoos, L., American Gas & Elec. Service Corp., New York, N. Y.
Hollenback, L. E., Veterans Administration, Northport, N. Y.
Lanigan, C. E., Sperry Gyroscope Co., Garden City, N. Y.
Lawrence, N. S., 170 Lincoln Ave., Newark, N. J.
Looze, G. E., American District Teleg. Co., New York, N. Y.
Mann, J., 4 Park Place, Hempstead, N. Y.
Maury, E. S., Lt., SCEL, Fort Monmouth, N. J.
McQuade, F. J., Board of Transportation, New York, N. Y.
Miles, R. A., 407 East 69 Street, New York, N. Y.
Preuss, J. (re-election), Consolidated Edison Co. of N. Y., New York, N. Y.
Royer, G. E., Sperry Gyroscope Co., Inc., Great Neck, N. Y.
Scott, W. S., American Gas & Elec. Service Corp., New York, N. Y.
Stone, R., SCEL, Fort Monmouth, N. J.
Warren, H. H., The Elec. Storage Battery Co., New York, N. Y.

4. Southern

Best, E. J., Southwestern Gas & Elec. Co., Shreveport, La.
Cahn, A. S., Cahn Elec. Co., Shreveport, La.
Cambias, S., Jr., Mississippi Valley Elec. Co., New Orleans, La.
Cavanaugh, J. W., 4729 Baronne St., New Orleans, La.
Cochran, W. A., Jr., Alabama Power Co., Birmingham, Ala.
Early, E. D., Commonwealth & Southern Corp., Birmingham, Ala.
Hickey, W. H., Jr., Southern States Equipment Corp., Hampton, Ga.
Joseph, L. J., Delgado Central Trades School, New Orleans, La.
McHenry, G., Southern Alkali Corp., Lake Charles, La.
Oglesby, S., Jr., Southern Research Institute, Birmingham, Ala.
Roberts, J. W., Allis-Chalmers Mfg. Co., Chattanooga, Tenn.
Wade, N. W., Memphis Light, Gas & Water Div., Memphis, Tenn.

5. Great Lakes

Busch, W. C., Central Ill. Elec. & Gas Co., Rockford, Ill.
Chung, C. C., Chevrolet Detroit Forge Plant, Detroit, Mich.
Dickinson, E. H., Cutler-Hammer, Inc., Milwaukee, Wis.
Dobbin, R. G., General Elec. Co., DeKalb, Ill.
Elmergreen, G. L., University of Wisconsin, Madison, Wis.
Graettinger, A. H., Allen-Bradley Co., Milwaukee, Wis.
Hopkins, A. M., Northwestern Technological Inst., Evanston, Ill.
Howlett, C. A., General Elec. Co., Fort Wayne, Ind.
Johnson, J. F., Minnesota Pr. & Lt. Co., Duluth Minn.
Kershaw, F. D., P. R. Mallory & Co., Inc., Indianapolis, Ind.
Knutz, J. H. (re-election), Public Service Co. of Northern Ill., Evanston, Ill.
Lowe, J. R., Minnesota Mining and Mfg. Co., St. Paul, Minn.
Maxwell, J. R., Vern E. Alden Co., Chicago, Ill.
Peterson, V. H., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Rao, M. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Rehwaldt, K. A., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Roberts, F. B., The Austin Engineers, Inc., Detroit, Mich.
Smitkamp, C. J., General Motors Corp., Flint, Mich.

7. South West

Atkins, J. W., Jr., Gulf States Utilities Co., Beaumont, Tex.
Edwall, H. A., Trinity Portland Cement Co., Houston, Tex.
Francis, S. M., Jr., Westinghouse Elec. Supply Co., Little Rock, Ark.
Herman, G., Bemis Brothers Bag Co., St. Louis, Mo.
Hulan, G. R., Lower Colorado River Authority, Austin, Tex.
Noster, M. F., Southwestern Bell Tel. Co., San Antonio, Tex.
Reeves, J. W., Southwestern Bell Tel. Co., Dallas, Tex.
Senter, C. H., University of New Mexico, Albuquerque, N. M.
Wood, W. L., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Word, K. H., Southwestern Bell Tel. Co., Dallas, Tex.

8. Pacific

Chandler, M. (re-election), U. S. Naval Repair Base, San Diego, Calif.
Henry, J. A., Pacific Gas & Elec. Co., Emeryville, Calif.
Landsberger, A., Sawyer Elec. & Mfg. Co., Los Angeles, Calif.
Morris, F. W., Jr., East Los Angeles Junior College, Los Angeles, Calif.
Rist, P. E., Central Arizona Lt. & Pr. Co., Phoenix, Ariz.
Shaffer, B. B., Consolidated-Vultee, San Diego, Calif.
Wilgus, F. W., Phelps Dodge Corp., Clarkdale, Ariz.

9. North West

Johnson, A. K., Vanport Extension Center, Portland, Oreg.
Lillcberg, M. K., Boeing Aircraft Co., Seattle, Wash.
Ransom, J. C. W., United States Bureau of Mines, Pullman, Wash.
Smith, Walter R., Bobs Elec., Spokane, Wash.
Wiscombe, E. K., U. S. Bureau of Reclamation, Salt Lake City, Utah.

10. Canada

Brearley, R. J. (re-election), Gatineau Power Co., Ottawi, Ont., Canada.
Brennan, J. T., Bell Tel. Co. of Canada, Montreal, Que., Canada.
Cockburn, E. D., Amalgamated Elec. Corp., Ltd., Toronto, Ont., Canada.
Doherty, T. H., British Columbia Elec. Rwy. Co., Vancouver, B. C., Canada.
Kembley, R. A., W. Robinson & Son Converters, Ltd., Woodbridge, Ont., Canada.
Macpherson, H. W., The T. Eaton Co., Ltd., Hamilton, Ont., Canada.
McAllister, A. W., Amalgamated Elec. Corp. Ltd., Toronto, Ont., Canada.

Elsewhere

Castle, P. W., City of Birmingham Elec. Supply Dept., Birmingham, Warwickshire, England.
Chac L., M., Mexican Lt. & Pr. Co., Mexico, D. F., Mexico.
Cortes Magallanes, J., Cia. Distribuidora Westinghouse, S. A., Mexico, D. F., Mexico.
Del Valle L., E., Comision Federal de Electricidad, Mexico, D. F., Mexico.
de Rosenbaum, G. E. E., c/o SOGELEC, Jadotville, Belgian Congo.
Gnoutcheff, A., c/o SOGEFOR, Jadotville, Belgian Congo.
Holmes-Smith, E., British Thomson-Houston Co., Ltd., Rugby, England.
Hurtado, R. J., Int'l General Elec. Co., Maracaibo, Venezuela, S. A.
Kanungo, A., Indian Ordnance Factory, Bombay, India.
Nallaperumal, S., The Fertilisers & Chemicals, Travancore Ltd., Kundara, S. India.
Roebuck, A., 45 New Street, Mdina, Malta.

Total to grade of Associate

United States and Canada, 113

Elsewhere, 11

OF CURRENT INTEREST

Commercial Standards Asked for Color Television

After a year of intensive tests and public and private demonstrations, executives of the Columbia Broadcasting System believe that the purely experimental stage of color television is past and have petitioned the Federal Communications Commission to adopt standards for commercial application of the CBS color television system.

In applying for a hearing, Frank Stanton, president of CBS, made the point that, so long as color television remains on an experimental basis, the industry will be subject to uncertainty, and the investment of the public and the broadcaster in low-frequency black-and-white television may be in jeopardy. CBS tests indicate that the basic technical stages have been completed, Mr. Stanton stated, and further advances must be made under commercial conditions. "As the next step in making color television available to the families of America, it is essential that the commission authorize commercial operation of ultrahigh frequency color television stations," he declared.

CBS demonstrations during the year included successful operation of a complete sending and receiving system; successful use of telephone and coaxial land lines as a means of conveying color television pictures to distant transmitters for rebroadcast; 200 broadcast demonstrations attended by more than 2,700 representatives of the government, industry, education, and the press, and, recently, live pickup using an Orthicon camera.

Consumption of Electricity by Transit Lines up for 1945

Consumption of electric energy by urban rapid transit lines showed an increase of 26,000,000 kilowatt-hours in 1945 over 1944, according to the annual summary of operations of 1,253 urban transit companies compiled by the American Transit Association.

While total consumption of electricity by the entire industry declined slightly to 6,928,000,000 kilowatt-hours, it remained considerably above the years preceding the war. Since 1926, rapid transit consumption has increased steadily with interruptions only in the depression years and during the war.

Expansion of trolley coach operations in many cities has added to the power load, the association said. Trolley coach consumption of electric power has increased rapidly and without interruption since the inauguration of the modern trolley coach in 1928. In 1945, it amounted to 415,000,000 kilowatt-hours or about six per cent of the total for the industry.

The report revealed that more than nine million dollars will be spent this year for new trackless trolley coaches and an additional 12 million dollars will be spent for new power and line construction; 22 million will be spent for new street cars, the report stated.

Power purchased from outside sources amounted to more than 69 per cent of the total consumption last year, while transit companies generated the remaining 31 per cent.

Fractional-Horsepower Motor Rating Standards Announced

A long-needed standardization plan for fractional-horsepower motors was announced by members of the motor and generator section of the National Electrical Manufacturers Association at a meeting held September 10, 1946, in New York, N. Y.

Fractional-horsepower motors now exist in such a variety of types and sizes with such differing characteristics for similar name plate data, that it is difficult to judge performance on that basis. Standards have been developed to eliminate these condition. Not only the users will benefit from the new NEMA standards, but also manufacturers and application engineers.

Most important in the new standardization plan is the basis for horsepower rating. Motors operating in the various speed ranges must meet specified breakdown torque requirements for each size. Breakdown torque is the maximum torque that a motor will exert without abrupt change in speed. Other specifications for rating include service factor and locked-rotor current maximums. Service factor is the inherent overload capacity, and, because of the relation between breakdown and full-load torque for small motors, it is higher (1.25–1.4) than the usual 1.15 value for larger ratings. Locked-rotor current standards are not new, having been adopted several years ago. C. P. Potter (F '29) chairman of the NEMA motor and generator section, presented the program of standardization.

The views on standardization expressed by various manufacturers stressed the importance of motor availability and volume production improvement, advantages to the makers, and ease of application. As a result of standardization, device and appliance manufacturers may obtain motors from a number of manufacturers and be assured of complete interchangeability, thereby assuring continuity of production in case of interruption of normal supply. Standardization and the accompanying reduction in variety of motors permits greater quantity production which results in a minimum cost. Ease of application is realized because the user is not forced to conduct exhaustive tests to determine which motor is best suited to his needs.

The standards announced are to be followed in November and December of this year by ones applying to dimensions and applications.

Sir James Jeans Dies in Surrey at 69

Sir James Jeans, physicist of international repute, well known for his interpretations of scientific concepts for the lay public, died in Surrey, England, September 17, 1946, at the age of 69.

Sir James' most original scientific work was done in cosmogony wherein he showed how gravitational instability in a chaotic mass of gas would give rise to the spiral nebulae, and how the same cause would lead to the formation of stars in the outer region of their spiral nebulae. For the laity he undertook the explanation of relativity, the quantum theory, radioactivity, atomic energy, and the transmutation of the elements.

He subscribed to the doctrine of the ultimate death of the universe, thinking that the human race was destined to die of cold while a greater part of the substance of the universe still remained too hot for life to obtain a footing. His philosophic view of modern science based it on the "uncertainty principle" which showed that determinism and cause and effect did not operate in the physical universe.

In response to an invitation from Woodrow Wilson, then president of Princeton University, Sir James joined that university in 1905 as professor of applied mathematics. Five years later he returned to Cambridge, where he lectured in mathematics for two years. He served as secretary of the Royal Society from 1919 to 1929 and also as professor of astronomy at the Royal Institution. He was knighted in 1928 and received the Order of Merit in 1939.

Among his expositions of modern physics are: "Astronomy and Cosmogony," the "Mysterious Universe," the "New Background of Science," "The Universe Around Us," and "Through Space and Time."

New Dielectric Wins Stalin Award. Discovery of a new dielectric substance by Professor Bentsion Vul, Soviet physicist and head of the laboratory of dielectrics in the Institute of Physics of the Russian Academy of Sciences, has been recognized by the award of the Stalin prize. The new substance, barium titanite, which possesses an unusually high dielectric constant, offers resistance to wide temperature changes.

Exhibitors Register for Electrical Engineering Exposition

Enrollment of a variety of exhibits, with many classifications represented by more than one exhibit, is reported by the International Exposition Company which is managing the Electrical Engineering Exposition to be held in the 71st Regiment Armory, New York, N. Y., concurrently with the 1947 AIEE winter meeting.

Nearly 100 classifications appear in the prospective list of exhibits which broadly includes electric generating and power station equipment, transmission lines and networks, substations, distribution, and maintenance. Typical of products of interest to public utilities, electrified railroads, and large industrial concerns are: generators, motors, batteries, switchboards and switchgear, solenoids, resistors, relays and regulators, rheostats, capacitors, commutators and circuit breakers, lamps and lighting fixtures for commercial and industrial uses, panelboards, gauges, and recorders. Items pertaining to transmission, distribution and load connection included cable and wire, insulators, conduits and duct, potheads, preservatives, reel racks, splices, substations, towers, transformers and converters, cutouts and fuses, motor generators, testing sets, surge protection, welders, switches, starters, and tools.

Both redesigned and newly designed equipment will be displayed at the exposition. It is expected that by the first of the year, when the exposition is held many of the engineering aspects of the postwar confusion in industry will be clarified, so that requirements arising from changes in the character of demand, expansion of networks, and new installations will be apparent. A great deal of material not now available will be placed on view, a number of items being exclusive to this display. Headquarters of the International Exposition Company are in the Grand Central Palace, New York.

Instruments in Airplanes Read From Ground by Television

"Television-telemetering," a war-developed method of checking from the ground test data in an airplane in flight, which can be extended to the testing of robot airplanes and guided missiles, recently was described by the Farnsworth Television and Radio Corporation.

The process was worked out by the Farnsworth corporation in co-operation with the Curtiss-Wright Corporation and the Navy Department. It enables observers at a ground station to see by television all instruments recordings and indicators of pressures, strains, and structural failures of a test airplane in the air. For a permanent record the data recorded on the telebiation receiver is filmed as it appears on the screen.

As used by the Navy, the system consisted of a television theater and television transmitter in the airplane and a mobile television receiving unit on the ground. The television theater was a panel on which were mounted dial-type instruments, rows of small galvanometer light-beam indicators, and breakage indicator lights. The panel was faced by a 23-tube television camera which transmitted a complete image of the panel to the ground station.

The television theater and camera-transmitter units were locked together in a sealed aluminum pressure box kept to a nearly constant temperature. The box was designed to operate at an altitude of 60,000 feet. Coupled to the power amplifier, the transmitting antenna projected back from the tail of the fuselage. In this position it was in free space and only rarely affected by shadows cast by the airplane.

The mobile ground station contained a receiving unit which provided a 350-line picture, a recording unit to film all transmissions, and equipment for two-way voice radio communications with the airplane in flight. Folding antennas were mounted on the roof.

Telecommunications Conference. The United States is issuing invitations, through the International Telecommunications Union at Berne, Switzerland, for a world telecommunications conference to be held in Washington, D. C., April 15, 1947, the State Department has announced. The conference will consider revision of the Madrid Telecommunications Convention of 1932. The following countries already have indicated that they would accept:

Canada, China, Colombia, Cuba, Dominican Republic, Ethiopia, Finland, Haiti, Italy, Lebanon, New Zealand, Panama, Paraguay, Poland, Siam, Syria, Turkey, Uruguay, Vatican City, and Venezuela.

November 15 Deadline for EJC Survey. A reminder of the November 15 deadline for the return of the questionnaire on the economic status of the engineer has been issued by Engineers Joint Council which is conducting the survey jointly with the United States Bureau of Labor Statistics. Engineers who have not returned the questionnaire are asked to do so before the deadline date. Results of the questionnaire will be tabulated immediately after November 15, and Andrew Fraser of Washington, D. C., who has been engaged as consultant and liaison with the Bureau of Labor Statistics, will proceed with preparation of a report based on the replies.

Mexican Engineers Honor Steinberg. Dean S. S. Steinberg of the University of Maryland College of Engineering has been notified by President Alfonso Castello of the Association of Engineers and Architects of Mexico of his unanimous election as an honorary member of that association and as its representative to the engineering organizations in the entire Western Hemisphere in all matters dealing with closer cultural and professional co-operation. This is the fifth country that has so honored Dean Steinberg, who last year made a good will tour of Latin America for the Department of State. The others are: Ecuador, Chile, Argentina, and Uruguay.

RESEARCH . . . .

Associated Universities, Inc. Forms Atomic Research Center

The former Army camp at Camp Upton, N. Y., is being transformed into an atomic research center, Brookhaven National Laboratory, under the sponsorship of an organization of nine universities, Associated Universities Inc., Doctor Philip M. Morse, director of research for the new institution, has announced. Peacetime applications of atomic energy will be the primary purpose of the project. Funds for the center are being supplied by the United States War Department, which is making an initial appropriation of $5,000,000.

A cyclotron of 20,000,000 to 30,000,000 volts and possibly a large one of 500,000,000 volts and a synchrotron of comparable size, as well as a chain-reacting uranium pile, will be erected on the site. Ten to 12 buildings will house biological, chemical, physical, medical, and engineering research groups on the 3,700-acre tract.

The sponsoring universities are: Columbia, Cornell, Harvard, Johns Hopkins, Massachusetts Institute of Technology, Pennsylvania, Princeton, Rochester, and Yale. Edward Reynolds of Harvard is president of the new organization, and the scientists employed will not be limited to co-operating schools. In addition, arrangements are being made so that graduate students may carry on their thesis research at the laboratory and get advanced degrees from a university. Choice of the students will not be restricted to those attending the nine schools.

Army's Research Division Plans for Civilian Co-operation

The task of putting into effect the War Department's new research and development policy announced by General Dwight D. Eisenhower in April 1946 has been entrusted to Major General Henry S. Aurand as head of the newly created Research and Development Division of the War Department General Staff.

As director of the division, General Aurand is key figure in the War Department's application of national scientific resources to the solution of military problems. He is adviser to the Secretary of War and the Chief of Staff on all War Department matters relating to research and development.

The revised policy drawn up in April by General Eisenhower under which the new division is operating stresses the Army's realization of the need for continued peacetime reliance on civilian assistance in military planning as well as in the production

of weapons. Scientists and industrialists are to be given the greatest possible freedom in their research, and within the Army the responsibility for research and development are to be separated from functions of procurement, purchase, storage, and distribution, General Eisenhower has decided.

In line with this, General Aurand now is bringing into the new division on an annual rotation basis, a group of top-flight engineers and scientists recruited from the laboratories of educational institutions, foundations, and industries. They will assist him in the same manner as military personnel assigned to the division.

A War Department civilian panel of outstanding scientists and engineers is being created, representing both the natural and the social sciences. The members of this panel, individually and in groups, will collaborate in the solution of special planning and technical problems.

General Aurand is endeavoring to give freedom of research to the contractual relationship between the Army and the universities, industries, and foundations now conducting research and engineering for it. Within the limits of present laws governing government contracts, all possible freedom will be given. Furthermore, he is advocating a change in the contract law to permit even greater freedom to scientists and engineers.

Industrial Research Institute at Stanford. Establishment of Stanford Research Institute, a nonprofit organization, which will carry on research projects for industry on the Pacific Coast, has been announced by Doctor Donald B. Tresidder, president of Stanford University. Conceived with the aid of leading industrialists of southern and central California and the Pacific Northwest, the institute will be located on the campus of Stanford University and will include within its scope pure and applied research in the physical, biological, and social sciences and in engineering and the mechanical arts. Director of the institute will be Doctor William F. Talbot, president and technical director of the fine chemicals division of the Sun Chemical Corporation.

Admiral Assails Naval Research Cut. Profound discouragement with what the Bureau of the Budget is doing to the Navy was given by Rear Admiral Luis de Flores, Deputy Chief of Naval Research, as one reason for his retirement on October 1. Admiral Flores, Deputy Chief of Naval Research, returned to the presidency of his own consulting engineering firm in New York, N. Y. "It is heartbreaking to me," he said, "to see what is happening to the entire military and Navy establishment now, particularly when national security is so extremely vital." He asserted that the new technological age has forced a staggering research and development job, amounting almost to complete reconversion, on the Navy and that the $45,000,000 which has been granted to do that job "is like handing over a hairpin with which to pick the lock of the gold vaults at Fort Knox."

INDUSTRY.....

New Steel-Frame Motor Manufactured by Westinghouse

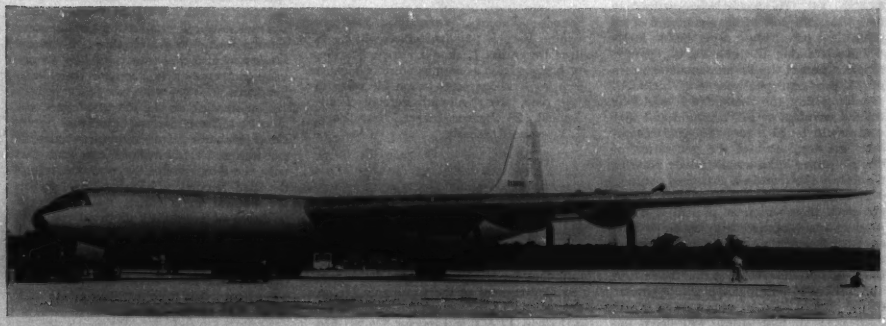
The Westinghouse Electric Corporation has introduced a new line of integral-horsepower steel-frame squirrel-cage induction motors which is called an unusual advance above the normal rate of progress.

Some of the major construction features claimed in the new motor are decreased size and weight, increased strength and shock resistance, interchangeability of parts, more easily installed coils, prelubricated ball bearings, and improved appearance. Vibration and noise also have been reduced.

An outstanding factor in the improvement of the motor is the substitution of steel in place of cast iron for parts such as end frames and pedestals. Size reduction of about 35 per cent and in some designs weight reduction of 50 per cent is reported. Much of the size and weight reduction is possible because dimensions of the formed steel parts can be held within closer limits than cast iron parts, thereby eliminating the large allowances necessary to establish minimum clearances. Also contributing to the size and weight reduction is an improved cooling system which requires less heat transfer surface.

Replacing cast iron with steel has resulted in a motor of greater strength and ruggedness, because the structural sections are as thick as those made of cast iron. Increased ruggedness is related directly to

Six-Engine Airplane Has Special Landing Problems



The world's largest airplane, the Army Air Forces' Consolidated-Vultee XB-36, is shown at the manufacturer's Fort Worth, Tex., airfield, one of the three in the United States equipped with the 300,000-pound runways which the B-36's 278,000-pound gross operating load requires. The other fields are the Fairfield-Suisun Army Air Base, northeast of San Francisco, and the Air Forces Proving Ground, Eglin Field, Fla. For a better distribution of weight during landing operations, future models of the B-36 will have four wheels to each main landing gear strut, and two for the nose wheel. The craft has an over-all length of 163 feet and a wing span of 230 feet. It is powered by six Pratt and Whitney engines producing a total of 19,000 horsepower. Its fuel capacity makes possible nonstop flights of more than 10,000 miles

the ability of steel to resist shock better than cast iron. Improved appearance is possible because formed steel presents a much smoother surface than cast iron.

Extensive interchangeability of parts makes possible several types of motors which utilize the same basic frame, stator, and rotor. It is a simple matter to convert an open-protected or dripproof motor into a splashproof or a totally enclosed fan-cooled motor by changing end brackets, hoods, and fans.

Decreased maintenance requirements have been achieved through simplification of winding installations and use of prelubricated ball bearings. Most winding failures are traced to damage incurred during insertion of coils in their slots. Design of the new motor incorporates slot shapes and sizes which permit easier installation of coils with shortened end extensions, thereby reducing damage to insulation.

Electric Power From Atomic Energy Held Feasible

According to a report made to the Westinghouse Electric Corporation by Doctor J. A. Hutcheson (M '44) associate director of the research laboratories and C. F. Wagner (F '40) manager of the central station engineering department, the economical production of electric power from atomic energy may not be far off.

The report compares the costs of an atomic-powered and a coal-fired power plant and concludes that technical problems rather than economic ones are the problems which must be solved before the atomic power plant is practical. For purposes of comparison the report assumes that an atomic powered 100,000-kw plant would be built in which the cost of the equipment and plant necessary to provide steam for the turbines would be about $12,000,000. This would be approximately four times the cost of the steam end of an equivalent power plant using coal as fuel.

In calculating the cost of the power, amortization of the investment at the rate of 15 per cent per year was included. Assuming that the atomic fuel would be refined uranium at $20 a pound and that coal would be $5 a ton, the report calculates the total cost of the generation of electric power in an atomic power plant to be slightly less than in a coal fired plant.

It is inferred that the heat given off by the stock piles which at present is a by-product and is carried away by air or by a stream of water must amount to many thousands of kilowatts of power. From this the assumption it follows that the earliest applications of atomic power will be similar to the present method of obtaining power from coal, in that steam will drive the turbine and that heat liberated from the fission of some material will be used to form the steam.

Problems new to the electrical industry will be those presented by the replacement of the present boiler and coal combustion equipment with some suitable heat exchanger and atomic power equipment. Special shielding equipment to confine dangerous radiations emanating from the uranium fuel will be needed. Since the steam passing through the turbine probably will be radioactive as well as the by-products of fission, special methods for handling, storing, and removing them will be needed.

Mexican Electrical Company Organized. Formation of Industrial Electrica de Mexico, S. A., has been announced by the Westinghouse Electric Corporation, Pittsburgh, Pa., with which the new company has a long term license agreement providing that the Westinghouse corporation will supply specifications and drawings for all products manufactured, as well as information on production methods. Personnel training for the new company also will be undertaken by the Westinghouse corporation which will bring groups of trainees to the United States. The Mexican company, which will be located north of Mexico, D. F., has a capitalization of $15,000,000, one third of which has been loaned by Nacional Financiera, an agency of the Mexican Government, and two thirds of which has been subscribed equally by Mexican and United States investors. The products to be manufactured include such basic equipment as transformers, circuit breakers, panelboards and distribution panels, motors, and controls, as well as household appliances. Limited production at the plant is expected to begin by the end of 1946, and the estimated demand for the company's products is about $10,000,000. J. W. White (A '29) formerly president and general manager of the Westinghouse Electric International Company, New York, is director general of the new company.

French Patent Warning. Americans owning French patents, which will be in force December 1, should file applications for prolongation as soon as possible because such applications must be on file prior to that date, the National Foreign Trade Council, 23 Beaver Street, New York, N. Y., warned recently.

Argentina Purchases IT & T Subsidiary. Argentine President, General Juan Peron, and Colonel Sosthenes Behn, president of the International Telephone and Telegraph Company, recently completed negotiations for the purchase by the Argentine Government of the Compania Union Telefonica, IT &T subsidiary. By terms of the sale, IT &T will receive $94,991,324 for its common and preferred stock holdings and two ten-year contracts giving it exclusive right to supply telephonic equipment to its former subsidiary and making it technical adviser in the operation of the system. The Argentine Government also will assume debentures which are outstanding in the Argentine, Swiss, and Swedish markets. At the ceremony marking the transfer of ownership, which was attended by United States Ambassador George S. Messersmith, Colonel Behn praised the Peron Government for repatriating "foreign owned public services by means of across-the-table dealings rather than by recourse to expropriation proceedings."

EDUCATION . . .

Scientists Ask Safeguard From Domination by Government

That American universities must beware lest Government funds granted for research become a controlling influence on those institutions was the consensus of the scientists attending the Princeton University bicentennial conference on the future of nuclear science.

The risk the universities run in accepting Government funds was emphasized by Doctor L. I. Rabi, professor of physics at Columbia University, who stated that there would be no better way for the Government to gain control of the universities than by the contribution of large funds for research.

"It would be a pity," he said, "if the full support which is available in certain fields of research serves to divert some scientists from following the full play of their imaginations. It would make for far healthier conditions, if the Government funds which have been made available for research were more in the nature of general grants rather than for specific objectives, and if the funds could be used in the same way as ordinary research funds."

In the discussion from the floor by scientists and educators, there was general agreement with Doctor Rabi. It was suggested by various speakers that universities must set the terms on which they will accept funds and also that they must look to private endowments to preserve their independence.

Commenting on the scientists' fears, the *New York Herald Tribune* noted that one of the chief characteristics of modern scientific research is its tremendous cost and that only the Government disposes of funds of the size needed. Granting that doubts are natural to scientists trained in the tradition of privately supported research, the *Tribune* concludes, however, "The trend (to Government support) is there and the fears are there; one can only hope that a Government, more enlightened in this respect than it has been in many others, will prove the fears unjustified."

Graduate Division in Mathematics. Brown University has announced the formation of a graduate division of applied mathematics as an interdepartmental project of the departments of physics and mathematics. Instruction will stress re-

search for advanced students in engineering, physics, and mathematics. Undergraduate students who have superior records in two of the three fields occasionally will be admitted. Fellowships for the studies have been provided by the Rockefeller Foundation through the academic year 1950–51.

JOINT ACTIVITIES

Washington Award Commission. Composition of the Washington Award Commission for 1946–47 has been announced by the Western Society of Engineers. Representatives of the societies making up the commission are:

Western Society of Engineers

F. G. Gordon, M. M. Leighton, William V. Kahler (M '39) *chairman;* C. Earl Webb, Philip Harrington, Homer K. Smith (F '44), P. R. Elfstrom, H. H. Morgan, J. deN. Macomb.

American Society of Civil Engineers

Ralph H. Burke, C. B. Burdick.

American Institute of Mining and Metallurgical Engineers

G. P. Halliwell, J. E. Drapeau, Jr.

American Society of Mechanical Engineers

John R. Michel, Ralph E. Turner.

American Institute of Electrical Engineers

Harry B. Gear (F '20), M. S. Coover (F '42).

OTHER SOCIETIES •

Societies Hold Concurrent Meetings. The 1946 winter meetings of the Electron Microscope Society of America and the American Society for X-ray and Electron Diffraction will be held in Pittsburgh, Pa., from December 5 to 7, at the Mellon Institute of Industrial Research. Joint sessions of the two societies may be arranged if the programs so permit. Joint dinners for December 5 and 6 already have been planned. Information concerning these meetings may be obtained from Doctor S. S. Sidhu, local chairman of the ASXRED, University of Pittsburgh, or from Doctor Earl A. Gulbransen, local chairman of the EMSA, Westinghouse Research Laboratories, East Pittsburgh, Pa.

Future Meetings of Other Societies

American Welding Society. Annual meeting, November 17–22, 1946, Atlantic City, N. J.

American Society for Testing Materials. Spring meeting and committee week, February 24–28, 1947, Philadelphia, Pa.

National Electrical Contractors Association. Annual meeting, October 14–18, 1946, Atlantic City, N. J.

National Exposition of Power and Mechanical Engineering. December 2–7, 1946, New York, N. Y.

National Research Council. Conference on Electrical Insulation, November 7–9, 1946, Johns Hopkins University, Baltimore, Md.

Chemical Society Employment Service. Organization of a nation-wide employment service for the chemical profession in seven key cities has been announced by Alden H. Emery, national secretary of the American Chemical Society. Through the facilities of the offices, an employer anywhere in the United States can obtain information about any chemist or chemical engineer in the country who is seeking employment by visiting the nearest regional office. Records of all registrants are available in duplicate form at all seven offices. To assure uniformity of information, all application forms are sent to Washington, where they are processed, numbered, and duplicated. Index cards giving the principal facts about the registrant are prepared, one being placed in an alphabetical file and duplicates in various sections of an experience file, according to the fields of specialization in which the applicant has indicated training or experience. The service has its headquarters in Washington, D. C., and maintains offices in New York, N. Y.; Atlanta, Ga.; Boston, Mass.; Chicago, Ill.; Houston, Tex.; and San Francisco, Calif.

International Standards Association. P. G. Agnew (M '19) secretary, American Standards Association, and E. C. Crittenden (F '44) assistant director, National Bureau of Standards, were the American delegates to the conference setting up the International Standards Association. Twenty nations were represented at the conference which met in London, October 14–26.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Carrier Supervisory Control of Pumping Station

To the Editor:

The valuable technical paper by W. A. Derr, W. A. Keller, and H. A. W. Hedke, (*EE, Nov '46, pp 699-705*) omits certain background material that is needed for its proper evaluation.

First of all, the adoption of carrier supervisory control for the pumping station of the United States Sugar Corporation in Lake Okeechobee, Fla., is an excellent example of the adage that an engineer's best friend is a competent sales engineer.

Trouble arose in 1943–44 over obtaining authority from the War Production Board for the copper needed in the power and control cables that were first proposed. The J. B. McCrary Engineering Corporation, Atlanta, Ga., was preparing detail drawings and specifications for the water-treatment plant and its lake pumping station. I was employed as engineer for Bitting, Inc., New York, N. Y., which at that time was supervisory manager for the sugar corporation. Sales representatives of the Westinghouse Electric Corporation came to me in Atlanta and to the engineers of the J. B. McCrary Engineering Corporation, in the winter of 1943–44, with the proposal that carrier current be tried. An investigation showed its probable merit. J. H. Temple and B. E. B. Snowden, engineers for McCrary, and I joined in the preparation of a discussion of the cost, copper required, and advantages and disadvantages of the various methods that might be used in controlling the pumping station in its possible locations on the shore and in the lake. This discussion when presented to WPB resulted in the approval of carrier current because of the saving in copper. The cost incidentally was estimated as slightly less than other methods of control.

Secondly, Lake Okeechobee being shallow is particularly dangerous to life in a high wind, as bad wave action is quickly aroused. Such waves can be expected in frequent thunderstorms in the summer and of course in hurricane weather. Waves probably will sweep at times over the pumping station. Control of the equipment in the pumping station and methods of checking its satisfactory operation at frequent intervals were therefore necessary. The supervisory control permits, for example, the checking of bearing and cooling water temperatures.

Finally, the starch plant has a designed capacity of 120 tons daily of sweet-potato starch. Inability to operate such a plant in bad weather because of inability to control the pumping of water runs quickly into large sums of money. It was believed, further, that eventually water pumped from the lake would be sold to the City of Clewiston and thus a human and fire hazard was introduced if water was not obtainable at all times. Fire insurance rates at the starch plant and in the City of Clewiston on company property and on employee's homes also were involved. These factors justified extraordinary measures to assure uninterrupted operation of the pumping station.

GREGORY M. DEXTER

(Consulting engineer, 32 Fenimore Road, Scarsdale, N. Y.)

NEW BOOKS . . .

"Considérations sur le Problème de la Stabilité Contribution a l'Etude des Régulateurs de Vitesse (Considerations of the Problem of Stability, A Contribution to the Study of Speed Governors)." The author of this text is well known for his work on hydraulic problems—in particular the joint publication of this author, and Jules Calame, "Theory of Surge Tanks." The present work deals first with the elementary theory of the regulation of water turbines, neglecting water hammer, and then with the effect of water hammer on the regulation, a particularly interesting chapter being devoted to the study of the effect of a sinusoidal movement of the governor. The author shows that the result is a sinusoidal pressure oscillation, out of phase with the governor movement. From this follows an analytical discussion of the effect of water hammer on the regulation, and of the conditions necessary for hydraulic stability. A chapter of particular interest to electrical engineers concerns the vectorial treatment of the conditions of stability. A chapter is devoted to the regulation of two or more units operating in parallel. Governor accessories and variants in governing procedure are given a chapter to themselves. Three appendixes are devoted to overspeed due to dropping load, penstocks of multiple characteristics, and the measurement of the characteristic time of promptness of response. The work is marked by clarity and thoroughness, even to the point of some repetition. The author is connected with a large European turbine manufacturer, and this reviewer would hazard the supposition that the book is the result of considerable experience with cases of difficult hydraulic conditions leading to actual or potential instability. It is regrettable that actual examples of such conditions are not illustrated more fully along with the means adopted to overcome them. The European engineer is perhaps more conscious of the threat of hydraulic instability than is the American engineer, whose machines in nearly every case are tied in to state-wide or region-wide networks, and specific examples of instability which may have arisen in European practice could be most informative. By Daniel Gaden. Editions la Concorde, Lausanne, Switzerland, 1945, 6¼ by 9¼ inches, 253 pages, illustrated, paper 21 Swiss francs, cloth 27 Swiss francs. (Review contributed by Robert A. Sutherland of Ebasco Services Incorporated, New York, N. Y.)

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ENDLESS HORIZONS. By V. Bush. Introduction by F. B. Jewett. Public Affairs Press, Washington, D. C., 1946. 182 pages, portrait, 9¾ by 6 inches, cloth, $2.50. Ranging from the quietly humorous "The Inscrutable Past" to the practically suggestive "Science for World Service," these forward-looking 17 papers demonstrate the versatility of Doctor Bush. In the varied fields under consideration, shortcomings are demonstrated, present achievements are assessed, and remedies and goals are proposed.

LEGAL PHASES OF CONSTRUCTION CONTRACTS. By I. V. Werbin. McGraw-Hill Book Company, New York, N. Y., and London, England, 1946. 267 pages, 8½ by 5¾ inches, cloth, $2.75. The author discusses 46 different legal problems that have arisen in connection with construction contracts, of practical interest to engineers, architects, contractors, and attorneys. The book shows the court precedents that have been established on these problems and gives, in many cases, the actual language of the contract provisions and also the facts involved. The intent is to provide the layman without legal training or experience an understanding of the import of the courts' decisions.

LINCOLN'S INCENTIVE SYSTEM. By J. F. Lincoln. McGraw-Hill Book Company, New York, N. Y., and London, England, 1946. 192 pages, illustrated, 9 by 5¾ inches, cloth, $2. Incentive management, as outlined in this book, goes beyond the ordinary conception of incentive pay. It is a philosophy of industry and life, which starts with the needs of society and depends primarily for its success on the development in the individual of his latent abilities. It is not only a method of wage payment; it is an economic system. The book presents exact data and results of the application of the system and demonstrates how it can be put into effective use in any plant.

QUARTZ CRYSTALS FOR ELECTRICAL CIRCUITS. By R. A. Heising. D. Van Nostrand Company, New York, N. Y., 1946. 563 pages, illustrated, 9¼ by 6 inches, cloth, $6.50. The piezoelectric property of quartz has caused a rapid growth in recent years in the use of quartz plates in electric circuits, particularly for radiotelephony. Some 16 specialists have contributed the separate chapters of this book, discussing the development of this application of quartz crystals, demonstrating methods for determining their desirable qualities, and describing the manufacturing and testing processes by which they are made effective for the purpose. The mounting of quartz plates is covered in detail, and their plating with thin metal films for use as electrodes is given special consideration.

SOUL OF LODESTONE. By A. Still. Murray Hill Books, New York, N. Y., and Toronto, Ontario, Canada, 1946. 233 pages, 8½ by 5½ inches, cloth, $2.50. A companion volume to the author's "Soul of Amber," this book does for magnetism what the previous book did for electricity. It provides a history of man's thoughts concerning magnetism and of the uses to which it has been put, beginning with the very earliest records and carrying on up to the point where the ever closer relationship between electricity and magnetism becomes the science of electromagnetism. Considerable direct quotation brings out the flavor of the periods under consideration, and extensive notes and references are provided.

WHAT ARE COSMIC RAYS. By P. Auger. Translated from the French by M. M. Shapiro. University of Chicago Press, Chicago, Ill., 1945. 128 pages, illustrated, 7¾ by 5¼ inches, cloth, $2. This book presents a simple, straightforward account of all the major cosmic-ray phenomena for the reader who lacks a technical knowledge of physics. A translation from the original French, the new edition has been revised in the light of recent new discoveries and important changes in the field of cosmic rays. The history of the development of cosmic-ray research is reviewed in the early chapters, and a number of photographs of tracks of electrified particles included.

X RAYS IN PRACTICE. By W. T. Sproull. McGraw-Hill Book Company, New York, N. Y., and London, England, 1946. 615 pages, illustrated, 9 by 5¾ inches, cloth, $4. The history, fundamentals, and characteristics of X rays and X-ray spectra serve as the introduction to this comprehensive work. With emphasis on the practical aspects, the book proceeds with the generation, absorption, scattering, and diffraction of X rays; the measurement and recording of X rays; and descriptions of X-ray equipment. Particular applications dealt with include: industrial radiography, medical applications, crystallography, fluoroscopy, microradiography, and numerous minor uses.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers

Standard Code for Arc and Gas Welding in Building Construction. American Welding Society, 33 West 39th Street, New York 18, N. Y., 68 pages, 50 cents.

Surplus Property. War Assets Administration, Railroad Retirement Building, Washington 25, D. C., 29 pages.

Nucleonics. Based on material prepared under the auspices of the United States Navy Department. Progress Press, 2153 Florida Avenue, Washington 8, D. C., 38 pages, $1.

The Geiger-Muller X-Ray Spectrometer. By F. G. Firth. North American Philips Company, Inc., 100 East 42d Street, New York 17, N. Y., 8 pages, no charge.

What Switch Shall I Use? Delta-Star Electric Company, 2400 Block, Fulton Street, Chicago 12, Ill., no charge.

The Plastics Industry. By Barrett L. Crandall. Bellman Publishing Company, Inc., 83 Newbury Street, Boston 16, Mass., 36 pages, $1.

Electrical Porcelain. By John C. Lebens, Jr. National Electrical Manufacturers Association, 155 East 44th Street, New York 17, N. Y., 20 pages.

Model K, Dillon Universal Tester. W. C. Dillon and Company, Inc., 5410 West Harrison Street, Chicago 44, Ill., 15 pages, no charge.

A Procedure for Testing the Locking Effectiveness of Self-Locking Nuts and Related Fastening Devices. By J. A. Sauer. Elastic Stop Nut Corporation of America, 2330 Vauxhall Road, Union, N. J., 16 pages.

Handbook of Farmstead Wiring Design. Industry Committee on Interior Wiring Design, Room 2650, 420 Lexington Avenue, New York, N. Y., 55 pages, single copies 40 cents, quantity prices on application.

Articles and Books on Spectrography, 15 pages. **Articles and Books on Industrial Photo-reproduction,** 7 pages. Industrial Photographic Sales Division, Eastman Kodak Company, 343 State Street, Rochester 4, N. Y., no charge.

MIMA News. This is a new four-page quarterly published by the Magnesia Insulation Manufacturers Association, 1317 F Street, N. W., Washington, D. C., for those interested in heat insulation.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Carrier Supervisory Control of Pumping Station Over Power Cable

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THE PROCESSING of starch requires large quantities of water. Thus, when the United States Sugar Corporation recently added the processing of starch to their activities, it was natural to install their new plant, which makes use of sweet potatoes as the raw product, at Clewiston, Fla. Clewiston is located in the Everglades near Lake Okeechobee. Lake Okeechobee is a shallow lake but it covers an area of over 700 square miles, second in area only to Lake Michigan in the United States.

When the new starch plant was planned, it was calculated that the maximum daily demand for water would be 4,000,000 gallons with 3,000,000 of these gallons requiring purification before being used in starch processing. An analysis of the water of Lake Okeechobee indicated that the best source of water for the processing of starch on a purity and temperature basis was four miles from the levee of the lake. These findings resulted in the decision to build a concrete pumping station in Lake Okeechobee, four miles from the levee and a total of seven miles from the water treatment plant where the water is treated before being used in the starch processing.

A view of the pumping station is shown in Figure 1. The inside diameter of the station is 40 feet and the walls are $2\frac{1}{2}$ feet thick. The station is slightly over 40 feet from top to bottom with the water level normally being about 15 feet above the lower floor level.

Paper 46-174, recommended by the AIEE committee on automatic stations for presentation at the AIEE summer convention, Detroit, Mich., June 24–28, 1946. Manuscript submitted April 19, 1946; made available for printing May 29, 1946.

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A 24-inch-diameter cast iron pipe carries the water from the pumping station to the water treatment plant. The pipe is buried approximately four feet below the bed of the lake. A 75-horsepower electric motor and a 180-horsepower gasoline engine are used to pump water through the pipe. Electric power is fed to the pumping station from the water treatment plant over a 4,000-volt power cable which is laid in the same trench with the pipe.

The relative inaccessibility of the pumping station led to the decision to provide control of the pumping equipment from the water treatment plant rather than having an operator located in the pumping station.

The remote control of the pumping station could have been accomplished by means of wires in a submarine control cable which would have had to be installed in addition to the power cable, or by means of power-line carrier supervisory control operated over the power cable. Economic considerations led to the application of carrier equipment to the 4,000-volt power cable.

Figure 2 is a single line diagram of the essentials of the power system at the water treatment plant and at the pumping station. The connections of the carrier equipment to the power cable also are indicated.

No carrier line traps were necessary on this installation because the power cable is terminated with the electric motor at the pumping station and with an autotransformer at the water treatment plant.

New Features of Installation

This installation of carrier-operated supervisory control equipment incorporates quite a number of operating and design features not previously employed. Following is a list of these features:

1. Operation of power-line carrier equipment over a submarine cable.
2. The use of standard low voltage capacitors for coupling to the power line instead of standard coupling capacitors, thus making it possible to omit line tuning units.
3. The complete incorporation of power-line carrier equipment including coupling equipment in a metalclad switchgear assembly.
4. Selective telemetering through the

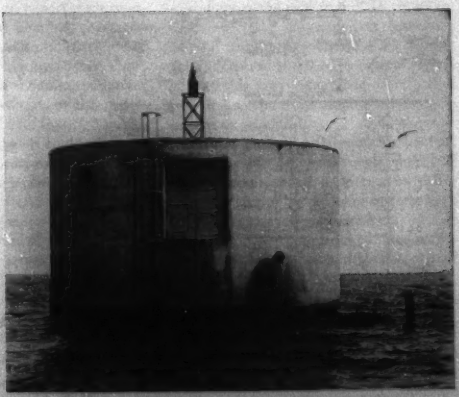


Figure 1. A view of pumping station showing entrance door

supervisory control equipment over a single-frequency power-line carrier channel without the use of audio tones for modulation of carrier.[1]

5. Establishment of communication circuit over single-frequency power-line carrier channel through supervisory control equipment.

Cable Characteristics

A total of 35,000 feet of 3-conductor power cable is used between the water treatment plant and the pumping station for the transmission of 4,000-volt 3-phase power.

A 22,800-foot length of armored submarine cable is used from the levee on the shore to the pumping station. The armored cable is laid in the same trench with the 24-inch water pipe. The submarine cable has number 4 conductors and is protected with number 8 Birmingham wire gauge galvanized armor. The outside diameter of this cable is approximately 2.06 inches. Figure 3 shows the construction of the armored cable.

A 12,200-foot length of rubber-jacketed cable is used from the levee, where it is spliced to the submarine cable, to the water treatment plant. This cable is laid in trenches across farm land at a depth of approximately four feet. No cover protection is used as this is below cultivating depth.

The characteristic impedance of ordinary high-voltage transmission lines is about 800 ohms for line-to-line channels and about 500 ohms for line-to-ground channels.[2] The characteristic impedance of both the armored and the jacketed cable used on this installation is approximately ten per cent of the usual values for ordinary transmission lines, the line-to-line impedance being approximately 85 ohms and the line-to-ground impedance being approximately 45 ohms.

When the carrier equipment was first placed in operation, the carrier sets were used to obtain a check on the line-to-ground attenuation values for the cable, which had been calculated previously from factory test data.

To obtain data necessary to check the factory test data, the carrier equipment at each location was set on the proper tap of the matching transformer to match the 45 ohms characteristic impedance of the cable. The accuracy of calculated attenuation values is dependent on having the line terminated in its characteristic impedance. The complex nature of the carrier receiver circuit makes it impossible to choose a setting which will provide exactly the right termination for all frequencies. However, because of the relatively high cable losses it was believed that only slight inaccuracies would result from the termination not being exact at all frequencies. The results obtained indicate that the carrier equipment provided satisfactory termination at all frequencies.

The carrier transmitter at the pumping station was adjusted to various frequencies with the high frequency voltage and

Table I. Calculated Decibel Loss for 4,000-Volt Power Cable (22,800 Feet Armored and 12,200 Feet Rubber Jacketed) From Field Data*

Frequency, Kc	Current Input	Voltage Input (E_1)	Voltage Output (E_2)	Impedance, Ohms	Total Decibel Loss	Decibel Loss Per Mile
175	0.515	22.8	0.38	44.3	35.56	5.37
165	0.510	23.2	0.58	45.5	32.04	4.83
150	0.520	23.3	0.79	44.6	29.40	4.43
135	0.520	23.6	1.02	45.4	27.30	4.12
120	0.515	24.5	1.30	47.6	25.50	3.85
105	0.490	23.7	1.95	48.3	21.68	3.28
90	0.510	24.5	2.85	48.0	18.68	2.82
75	0.530	26.4	4.20	49.8	15.96	2.41
60	0.540	26.2	5.50	48.5	13.56	2.05
50	0.535	28.1	7.07	52.5	12.00	1.81
40	0.560	26.2	8.40	46.8	9.88	1.49

* Decibel loss = $20 \log_{10} \frac{E_1}{E_2}$

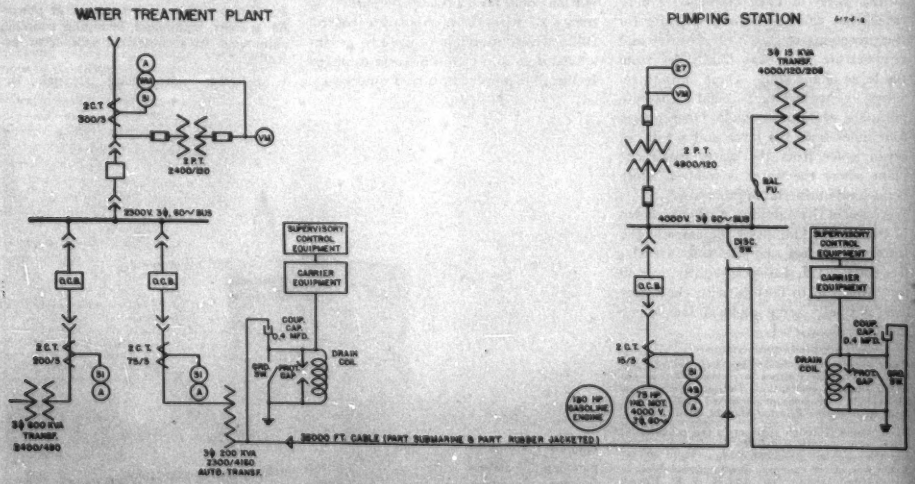


Figure 2. Single line diagram of power system at the water treatment plant and at the pumping station

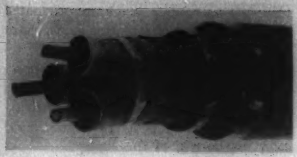


Figure 3. Cutaway view of armored submarine cable

current values being read for each different frequency. The output voltage also was read at the water treatment plant for each different frequency.

From the test data obtained it was possible to calculate the attenuation values of the cable at the various frequencies. Transmission losses usually are expressed in decibels. The decibel is expressed numerically as follows:[3]

$$db = 10 \log_{10} \frac{P_1}{P_2}$$

where

db = decibel loss (attenuation)
P_1 = power in
P_2 = power out

If the two points at which the voltage is measured have identical impedances, the decibel also can be expressed as follows:[3]

$$db = 20 \log_{10} \frac{E_1}{E_2}$$

where

db = decibel loss (attenuation)
E_1 = voltage input
E_2 = voltage output

Table I shows the readings of current and voltage as well as the calculated values of decibel loss and impedance. The values of impedance which were calculated from the voltage and current input readings indicate that the termination consisting of the carrier receiver at the water treatment plant was not exactly correct for all frequencies since the calculated impedance values should have been the same at all frequencies.

Curve *A* of Figure 4 shows the decibel loss for the entire cable plotted against frequency, the values used being those shown in Table I. The values for the entire cable check well with factory test data obtained prior to installation of the cable. The factory tests indicated somewhat higher losses for the submarine cable alone and somewhat lower values for the jacketed cable alone. Curve *B* of Figure 4 shows the decibel loss per mile of the submarine cable and curve *C* of Figure 4 shows the decibel loss per mile of the rubber jacketed cable. Curves *B* and *C* are plotted from factory test data.

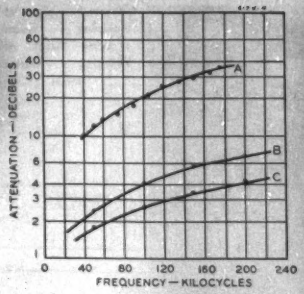


Figure 4. Curves of cable attenuation

A—Total decibel loss for entire cable from field data
B—Decibel loss per mile of submarine cable from factory test data
C—Decibel loss per mile of jacketed cable from factory test data

Carrier Coupling Equipment

A standard line of coupling capacitors is available for introducing carrier frequencies to power lines.[2] This line of coupling capacitors is available for system voltages from 15 kv to 345 kv. The desirability of keeping these coupling capacitors to a reasonable size resulted in their being designed with low values of capacitance. These low values of capacitance result in a relatively high capacitive reactance for even the carrier frequencies from 45 to 165 kc. Since the carrier sets are designed for matching a line impedance which is essentially resistive, a line tuning unit is used with the standard line of coupling capacitors to cancel the capacitive reactance of the coupling capacitor, thus making it possible to match the carrier sets to a resistive impedance.

The smallest carrier coupling capacitor which could have been used on this installation is for use on 15-kv lines. The size of this unit is such that it could not have been incorporated conveniently in the assembly of metalclad switchgear. Also, a line tuning unit would have been required since the capacitive reactance of this coupling capacitor at a frequency of 50 kc is 320 ohms whereas the characteristic impedance of the cable from line-to-ground is only 45 ohms.

Since the carrier equipment on this installation was to be operated from line-to-ground, it was decided to use a standard 2,300-volt capacitor similar to those used for power factor correction to couple the carrier equipment to the power cable. The capacitor chosen has a capacity of 0.4 microfarad. Due to the small size of this capacitor no difficulty was encountered in mounting it in the rear compartment of the metalclad switchgear unit which houses the supervisory control and carrier equipment. Figure 5 shows the capacitor mounted in the metal clad unit at the water treatment plant.

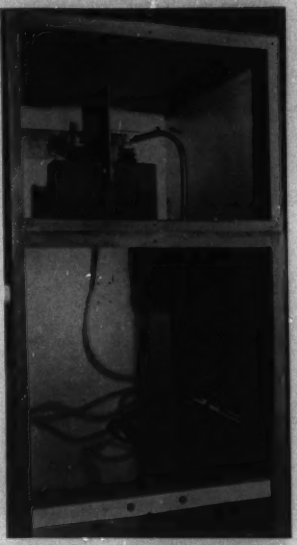


Figure 5. Rear view of metalclad unit with cover removed showing coupling capacitor

The capacitive reactance of the 0.4-microfarad capacitor which was used is only eight ohms at a frequency of 50 kc. This low value of capacitive reactance made it unnecessary to use a line tuning unit. The use of a 0.4-microfarad capacitor on this low voltage line results in a flow of less than 0.4 ampere of 60-cycle current to ground.

The carrier drain coil, grounding switch, and protective gap as shown in Figure 2, are all mounted on a protective panel mounted on the barrier between the high and low voltage compartments of the metalclad unit. The front of this protective panel can be seen near the top of Figure 6.

Carrier Equipment

The power-line carrier equipment on this installation is of the rack and panel

Figure 6. View at pumping station showing front of swinging carrier panel

type.[4] This type of construction makes it possible to build a unit for any carrier application, by making an assembly of the necessary standard panels. In this case a transmitter panel, receiver panel, and modulator panel were required at the pumping station and at the water treatment plant.

The carrier equipment at both locations is mounted on a swinging panel inside of one of the metalclad switchgear units. Figure 6 shows the front of this swinging panel at the pumping station.

The carrier equipment is operated from 125-volt batteries at each location. The carrier transmitters and receivers are adjustable over a frequency range from 45 to 165 kc. The transmitters have a nominal power output of 15 watts and operation is possible with the signal attenuated 30 decibels.

The transmitter panel consists of a Colpitts oscillator (one tube) and of a 6-tube push-pull amplifier. The amplified carrier frequency output is fed into an iron-cored radio frequency transformer whose secondary winding couples the carrier to the line through the coupling capacitor.

The receiver panel consists of a biased detector which is saturated when a satisfactory signal or a stronger than satisfactory signal is received. Thus, the plate current of the receiver is not materially altered for wide variations in received signal strength. The output of the detector supplies rectified current for the supervisory control receiver relay.

The modulator panel includes the matching transformers, resistors, and relays for modulating the transmitter for voice communication, for matching the carrier receiver to the telephone receiver, and for inserting attenuating resistance in the receiver circuit for improved communication.

On this installation both transmitters and both receivers are operated at the same frequency. The equipment is being operated at a frequency of 45 kc, since the attenuation in the cable is considerably less at lower frequencies.

Supervisory Control

The supervisory control equipment on this installation operates by means of coded impulses with each code transmitted being checked by a duplicate code originating at the other station. The impulses are transmitted at the rate of 15 per second and all selection and control impulses are of the same duration.

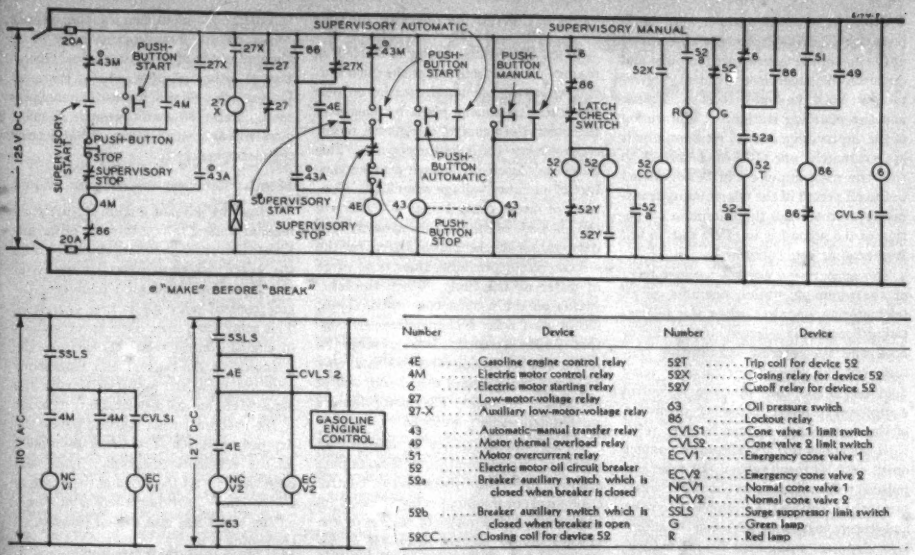
Carrier impulses are transmitted by the supervisory control equipment by having the supervisory control impulsing contact close the carrier keying circuit. All carrier impulses which are originated at either the pumping station or the water treatment plant result in the carrier receiver relay at both locations being operated since both transmitters and receivers operate on the same frequency. The carrier receiver relay is of the same general type as the rest of the supervisory control relays and is mounted in the supervisory control relay case.

Figure 7 shows the metalclad switchgear unit on which the supervisory control equipment is located at the water treatment plant. This figure shows the individual escutcheons or key and lamp plates for each of the functions performed by the supervisory control equipment as well as the supervisory control relay case and the water flow indicator.

The supervisory control equipment performs the following functions:

1. Start, stop, and supervise electric motor.
2. Start, stop, and supervise gasoline engine.
3. Control and supervise automatic–manual transfer.
4. Supervise electric motor annunciator.

Figure 7. Front view of carrier supervisory control unit at water treatment plant



Number	Device	Number	Device
4E	Gasoline engine control relay	52T	Trip coil for device 52
4M	Electric motor control relay	52X	Closing relay for device 52
6	Electric motor starting relay	52Y	Cutoff relay for device 52
27	Low-motor-voltage relay	63	Oil pressure switch
27-X	Auxiliary low-motor-voltage relay	86	Lockout relay
43	Automatic–manual transfer relay	CVLS1	Cone valve 1 limit switch
49	Motor thermal overload relay	CVLS2	Cone valve 2 limit switch
51	Motor overcurrent relay	ECV1	Emergency cone valve 1
52	Electric motor oil circuit breaker	ECV2	Emergency cone valve 2
52a	Breaker auxiliary switch which is closed when breaker is closed	NCV1	Normal cone valve 1
		NCV2	Normal cone valve 2
52b	Breaker auxiliary switch which is closed when breaker is open	SSLS	Surge suppressor limit switch
		G	Green lamp
52CC	Closing coil for device 52	R	Red lamp

Figure 8. Schematic diagram of automatic and manual control of electric motor and gasoline engine

5. Supervise gasoline engine annunciator.
6. Supervise burglar alarm.
7. Selective telemetering of rate of water pumped.
8. Establishment of communication circuits.

Communication

Communication between the water treatment plant and the pumping station is provided over the carrier channel through the supervisory control equipment. Picking up the telephone hand set at either location results in the proper selection codes being transmitted by the supervisory control equipment to ring the telephone bell at the location being called. The telephone bell continues to ring until the call is acknowledged by picking up the telephone hand set at the called location or until the telephone hand set is restored at the calling location. When the telephone hand set is picked up at the called location, the supervisory control equipment automatically locks out and the communication circuits are established. Push-to-talk communication is used since the carrier transmitters and receivers all are adjusted to the same frequency. When communication is established the carrier receivers are operated automatically on the linear portion of the detector tube characteristic curves so that undistorted demodulation can be effected.

The supervisory control equipment remains locked out until the telephone hand sets are restored. When both telephone hand sets are restored, the supervisory control equipment automatically unlocks and is ready immediately for other operations.

Telemetering

A recorder with a 7-day chart is installed in the pumping station to record the rate of water pumped in millions of gallons per day. This recorder operates on impulses received from a telemetering transmitter arranged to measure water flow by a venturi tube connection. The telemetering transmitter which is used to send impulses to the recorder also is connected to the supervisory control equipment so that a selective indication of rate of water pumped can be obtained at the water treatment plant over the supervisory control channel.

The telemetering equipment operates on the duration of impulse principle. Each cycle of the transmitter is divided into an on and an off period. Minimum reading is obtained on the receiver with minimum on period and maximum reading is obtained with maximum on period. The telemetering equipment used on this installation operates on a 5-second cycle. At zero water flow there is an on period of approximately 0.5 second and at a flow of water equal to full scale deflection on the receiver (15,000,000 gallons per day) there is an off period of approximately 0.5 second.

When the telemetering point is selected at the water treatment plant, the telemetering receiver is connected to the carrier receiver at the water treatment plant and the telemetering transmitter is connected to the carrier transmitter at the pumping station. The supervisory control equipment is arranged to be inoperative to the carrier impulses resulting from the operation of the telemetering transmitter, when the telemetering equipment is thus connected to the carrier channel. The indication of the amount of water being pumped may be retained at the water treatment plant as long as desired.

Release of the telemetering indication and restoration of the supervisory control equipment is effected by restoring the pull type selection key just as for the release of other functions. However, in this instance, keying of the carrier transmitter at the water treatment plant for the supervisory control reset impulse is automatically held off until completion of a

telemetering impulse, which may be in progress. The reset impulse is transmitted at the end of the telemetering impulse and operates the supervisory control receiver relay at both the water treatment plant and the pumping station. The duration of the supervisory control reset impulse is approximately one-fifth of a second so that the reset impulse can be completed in the off period of the telemetering transmitter even though the minimum off period of 0.5 second is in effect due to full scale reading being obtained.

The supervisory control receiver relay at the pumping station operates on all telemetering impulses when the telemetering function is selected. Operation of both the telemetering transmitter contact and the supervisory receiver relay does not allow the supervisory control equipment to reset. However, operation of the supervisory control receiver relay with the telemetering transmitter contact open, such as results when the reset impulse is transmitted from the water treatment plant, causes the equipment to reset and restore to normal, releasing the supervisory control equipment for other functions.

Control of Electric Motor and Gasoline Engine at Pumping Station

Figure 8 is a schematic diagram of the automatic and manual control for the 75-horsepower electric motor and the 180-horsepower gasoline engine which are used to pump water from the pumping station to the water treatment plant through the 24-inch pipe.

An automatic–manual transfer scheme which can be operated either from the water treatment plant or the pumping station by means of the supervisory control equipment is employed. A latching type relay 43 is used to effect this transfer. It is to be noted from the schematic diagram that the coils of this relay can be operated either from a push button station located at the pumping station or from supervisory control interposing relays.

When the manual contacts of the transfer relay 43 are closed, the electric motor and the gasoline engine are independently under the control of local push button stations and the supervisory control equipment. Thus, when on manual control, the operator at the water treatment plant can start or stop either the electric motor or the gasoline engine at will. Either unit can be operated to pump water or both units can be operated to pump water at the same time.

Manual Control of Electric Motor

When the electric motor is started on manual control from either the push button station at the pumping station or from the water treatment plant by means of the supervisory control equipment, motor control relay $4M$ is first energized. This relay seals itself in through a make contact of auxiliary voltage relay $27X$. Contacts of motor control relay $4M$ energize the solenoids of the normal and emergency cone values of the pump driven by the electric motor providing there is no surge of water at the time. When the limit switch on the normal cone valve closes, motor start relay 6 is energized. A contact of relay 6 completes the circuit to the motor breaker closing relay $52X$ and relay $52X$ in turn energizes the closing coil of the motor breaker. The motor thus is started and water is pumped.

If the electric motor is stopped by means of the push button at the pumping station, by the supervisory control equipment, or if voltage relay 27 closes its back contact due to loss of voltage or low voltage, motor control relay $4M$ is de-energized. This de-energizes the normal cone valve solenoid of the electric motor pump. When the limit switches on the normal cone valve open, the emergency cone valve solenoid is de-energized and motor start relay 6 is de-energized. A contact of relay 6 energizes the trip coil of the motor breaker, stopping the motor.

Emergency shutdown of the electric motor results if overcurrent relay 51 or thermal overload relay 49 operate. Operation of either of these relays energizes lockout relay 86 which must be manually reset. Relay 86 simultaneously de-energizes motor control relay $4M$ and trips the motor breaker.

Manual Control of Gasoline Engine

When the gasoline engine is started on manual control from either the push button station at the pumping station or from the water treatment plant by means of the supervisory control equipment, engine control relay $4E$ is first energized. This relay then seals itself in. Contacts of engine control relay $4E$ energize the solenoids of the normal and emergency cone valves of the pump driven by the gasoline engine and also complete a circuit to the gasoline engine starting panel, the detailed operation of which is not shown on the schematic diagram. Thus, the cone valves start to open and the gasoline engine starts providing there is no surge on the water line and the oil pressure of the engine is up.

When the gasoline engine is stopped from either the push button station at the pumping station or by the supervisory control equipment, engine control relay $4E$ is de-energized. When relay $4E$ is de-energized it immediately releases the solenoid of the normal cone valve of the pump driven by the gasoline engine.

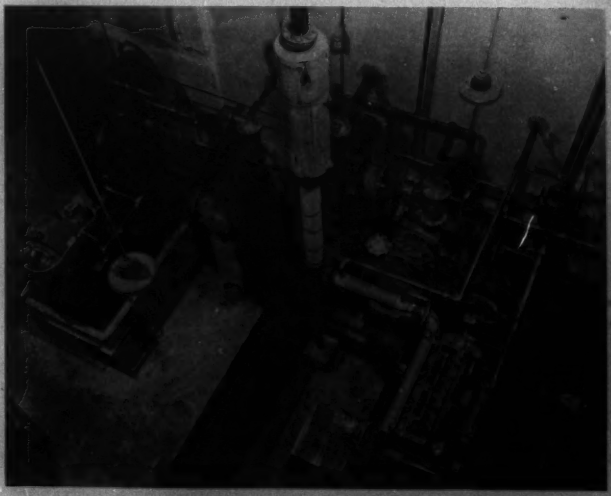


Figure 9. View showing electric motor and gasoline engine in pumping station

When the limit switch on the normal cone valve opens it releases the solenoid of the emergency cone valve and causes the engine control to transfer to the idling cycle.

Automatic Control

With the automatic contacts of the transfer relay closed, the electric motor will be running if there is voltage available and the lockout relay is not operated. When on automatic control the electric motor cannot be stopped from either the push button station or from the water treatment plant by means of the supervisory control equipment. If a transfer from manual control to automatic control is effected from either the pumping station or the water treatment plant the electric motor will start if it was not already running and the gasoline engine will stop if it was running.

If when on automatic control the 4-kv voltage should fail at the pumping station or the lockout relay 86 should operate, the electric motor is stopped and the gasoline engine is started automatically. If the electric motor stops as a result of loss of voltage and voltage again becomes available the gasoline engine automatically stops and the electric motor starts.

When on automatic control, either the electric motor or the gasoline engine will be running if conditions are satisfactory for either to be running, with preference being given to the electric motor. The electric motor and the gasoline engine never will pump water simultaneously when on automatic control.

Conclusions

Power-line carrier equipment has been applied to transmission lines for more than 20 years. The majority of the applications have been for protective relaying and communication with the carrier in most instances being operated over open construction transmission lines rated 33 kv or greater. While there is still much information to be obtained concerning operation of power-line carrier equipment over such lines considerable empirical data have resulted from tests made on some of these applications so that the performance of the carrier equipment usually can be predicted fairly accurately for proposed applications.[3]

Up to the present time there have been very few applications of power-line carrier equipment to low voltage lines. This is especially true in the case of power cable. The possibility of combined functions on carrier channels makes it economically sound to apply carrier equipment to lower voltage lines in many instances, and it is expected that there will be many such applications in the future. The results obtained on the installation described indicate that standard carrier sets which will operate through a 30-decibel loss can be operated over considerable distances of power line cable. There is a need for similar installation data on future applications so that operation over cable can be predicted as accurately as operation over open construction power lines.

This installation of power-line carrier on a low voltage line indicates that there will be many applications of carrier equipment to low voltage lines (either open construction or cable) where it will be desirable to consider coupling means other than the standard line of coupling capacitors from an economic and space standpoint.

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Factors Affecting Insulation Resistance of Large D-C Machines

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INSULATION RESISTANCE of rotating machines was considered by many to be a haphazard collection of unrelated numbers. One reason for this view was that insulation resistance readings rarely were taken under the same conditions. Many of the factors which greatly affect insulation resistance were not known. In the past decade, significant contributions have been made toward a better understanding of the problem.[1–4] The influence of insulation temperature, time of application, and magnitude of test voltage, moisture, and machine size were recognized.

Study of the problem by the AIEE subcommittee on insulation resistance has resulted in the preparation of a proposed "Recommended Practice for Insulation Resistance Testing of A-C Rotating Machines." Its purpose is to summarize existing knowledge, make specific recommendations for test procedures, and give minimum insulation resistance formulas for new machines. Reference to d-c machines was omitted because it was recognized that the problem on these machines in some respects was different, and that further study was necessary. It was hoped, however, that in the near future sufficient progress would be made on the d-c problem to permit extension of the proposed recommended practice to include both classes of machines.

To assist in this problem, insulation resistance data on new d-c machines over 1,000 horsepower have been accumulated by the authors and their associates over a 5-year period. The purpose of the present work has been to determine, from a statistical examination of these data, the relative effect of the principal factors which affect the insulation resistance of d-c machines. In addition to previously recognized factors, such as machine size and insulation temperature, the absolute humidity of the surrounding air has been found to have an important effect on the insulation resistance of commutator type machines. This study has led to the development of an insulation resistance formula for d-c machines which includes all of these factors. It has been recognized

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The authors gratefully acknowledge the assistance of the following people: A. M. Harrison for engineering guidance; Doctor Casper Goffman for advice and criticism in statistical problems; Henry Glitsch, James Nicalo, and Josephine Garber for assistance in the compilation of the data. All are of the Westinghouse Electric Corporation.

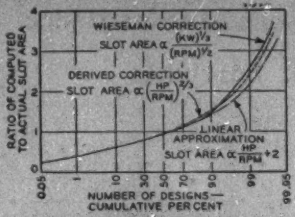

Figure 1. Frequency distribution of the ratio of computed to actual slot area showing correlation of various formulas

Data based on representative designs of 200 d-c machines of 100 horsepower and more

by the authors that for greatest usefulness, such a formula should express the relationship of the various factors in terms of simple arithmetical processes. Accordingly, a linear relationship involving rated horsepower, speed, and the winding insulation dimensions has been developed and compared to the existing formula. The correction factor for the effect of absolute humidity at the time of test, which has been included in the formula, is a new concept.

The factors which affect measured values of machine insulation resistance may be grouped as follows:

1. The nature and condition of the insulation material.
2. The design and construction of the machine.
3. The conditions of test.

Quantitative evaluation of the effect of these influences is difficult because of the complex structure of machine insulation. There is also a lack of basic knowledge of the fundamental processes involved and a lack of control of factors which have an important effect on machine insulation resistance.

Machine Insulation Structure

In general, insulation leakage between machine components may be segregated into two parallel paths, one through the body of the insulation itself, the other over the surface of the insulation. The relative magnitudes of the surface and volume leakage currents depend on the physical proportions of the insulation structure and the extent to which each is affected by existing conditions. It is usually difficult to determine the relative extent that each of these currents contributes to the total insulation leakage. In the case of stator windings of a-c synchronous and induction machines, it is perhaps reasonable to assume that surface leakage currents have a negligible effect on the total leakage current. Experience has shown, however, that at least under normal operating conditions the insulation resistance of d-c machines is determined largely by creepage factors. The same also appears to be true of new d-c machines under certain conditions of atmospheric humidity.

The basic difference between a-c synchronous and induction machines and d-c machines from an insulation standpoint is the existence of relatively large exposed creepage areas which are inherent in the design of d-c machines. This is caused principally by the commutator and to a lesser extent by the brush rigging, series, commutating, and compensating windings. Therefore, it is reasonable to expect that the insulation resistance characteristics of commutator type machines would be different from machines without commutators and that, in general, the commutator type machines would have lower values of insulation resistance.

Scope of Work

The insulation structure of large d-c machines usually consists of armature circuit insulation and shunt field insulation. The insulation resistance of the shunt field winding is usually relatively high. The armature circuit insulation resistance is of principal importance because it is usually lower and more affected by external conditions. The insulation of the armature circuit includes

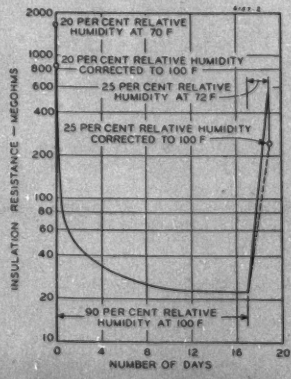

Figure 2. Insulation resistance decrease and recovery of a d-c armature exposed to 90 per cent relative humidity at 100 degrees Fahrenheit

that of the armature winding, brush rigging, series, commutating, and compensating windings. The scope of the present work has been to study and analyze the results of armature circuit insulation resistance measurements of approximately 1,100 d-c machines in the range of 1,000 to 7,000 horsepower. Although insulation resistance data were not available for machines of less than 1,000 horsepower, it was felt by the authors that the dividing line between small and large d-c machines should be 100 horsepower. Therefore, in the development of the size correction which is included in the suggested minimum formula, machines of 100 horsepower and higher were considered.

In this work effort was directed toward estimating from a statistical study of the insulation resistance data known design proportions of the machines and known conditions of test, the probable influence of the principal factors which contribute to the measured value of insulation resistance. A further purpose of this work has been to relate these factors into a simple usable formula for expressing expected insulation resistance of new machines in terms of parameters which are known or easily obtainable. In the development of the ideas advanced in this paper, only general purpose d-c machines of ratings of 100 horsepower or more were considered. The following, therefore, does not necessarily apply to special types of d-c machines such as are used in the traction field.

Development of Formula Relating Rated Horsepower and Speed to Machine Size

One of the factors which influences measured values of insulation resistance, which is not related to the nature or condition of the insulation, is the physical size of the machine. A major shortcoming of the present AIEE minimum insulation resistance formula is that it makes no significant allowance for this factor. More rational formulas were proposed in 1934 by Wieseman which take into account effective insulation area and thickness. Although basically sound, these formulas have not enjoyed widespread use, largely because of a general unwillingness to handle formulas involving fractional powers. For greatest usefulness in a practical insulation resistance formula, a relationship among the various factors which involve relatively simple arithmetical processes is desirable. Accordingly, an attempt has been made in this work to develop a linear formula for armature

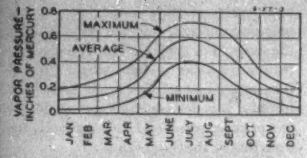

Figure 3. Record of the average and range of the daily vapor pressures for the Pittsburgh area for 1940 to 1946

circuit insulation resistance of d-c machines 100 horsepower and higher which includes the effect of machine size.

Under conditions where surface creepage is negligible, machine insulation resistance would be expected to vary inversely as the ratio of insulation contact area to thickness. Where surface creepage has an appreciable effect, the logic of making a size correction based on contact area, at first glance, would appear questionable. More careful analysis, however, reveals that there is a substantially linear correlation between contact area and effective creepage area. Therefore, even where surface creepage is not negligible, it appears that insulation contact area can be used as a basis for size correction.

The considerations involved and assumptions made in the development of a linear formula, relating machine size to rated voltage, horsepower, and speed are as follows:

1. The total insulation area under consideration includes that of all the windings in the armature circuit. In the development of the formula, only the insulation area in the armature slots is considered. The other areas involved are comparatively small and, in addition, are roughly proportional to the slot contact area.

2. The slot contact area of the armature is equal to the product of the slot perimeter, the number of slots, and the length of the armature iron.

3. Although slot insulation thickness is, in general, a function of voltage, the slot insulation thickness for large d-c machines is substantially constant. Therefore, rated voltage need not be included in the formula.

4. The machine output for a given temperature rise and average conditions of electric and magnetic loading is related to armature size by the following fundamental design relationship:

$$\frac{\text{Horsepower}}{\text{Revolutions per minute}} = K_1 d^2 l$$

where d and l are the armature diameter and length, respectively.

5. The slot depth is approximately constant.

6. An average value is assumed for the slot pitch (center to center distance between slots). Actually, this value may vary by a maximum of plus or minus 30 per cent.

7. An average value is assumed for the ratio of armature length to diameter. This value may vary by as much as plus or minus 80 per cent of the average value. Slot area, however, varies as the cube root of this ratio.

From the foregoing it follows that

$$\text{Slot area} = \frac{K_2 dl}{\text{slot pitch}} = K_2 dl = K_2 a d^3$$

where $a = l/d$.

$$\frac{\text{Horsepower}}{\text{Revolutions per minute}} \propto d^3 l \propto a d^3$$

$$d \propto \left[\frac{\text{horsepower}}{(\text{revolutions per minute})a}\right]^{1/3}$$

where d, l, and slot pitch are in inches, slot area is in square inches.

$$\text{Slot area} = K_4 \left[\frac{\text{horsepower}}{(\text{revolutions per minute})}\right]^{1/3} \quad (1)$$

The best linear approximation for equation 1 was determined and is as follows:

$$\text{Slot area} = K_5 \left(\frac{\text{horsepower}}{\text{revolutions per minute}} + 2\right) \quad (2)$$

Actually, the values K_4 and K_5 (equations 1 and 2) are not constants because of the assumption of average values for design factors which affect machine size without directly affecting machine output. Average values, however, were obtained by substituting actual slot areas of 200 representative designs into the formula and solving for K_4 and K_5 in equations 1 and 2. The averages thus obtained for K_4 and K_5 were found to be 4,800 and 1,500, respectively.

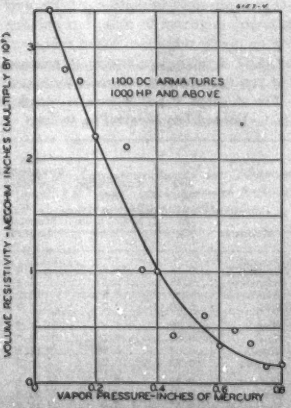

Figure 4. Correlation of median value of volume resistivity with vapor pressure at time of test

The validity of the foregoing formula was checked by comparing the ratio of computed to actual slot areas for each formula. The computed ratios for the 200 representative designs were arranged in increasing order and plotted on arithmetic probability paper (see the appendix). Figure 1 shows a comparison of correlation for equations 1 and 2 as well as the Wieseman formula for 200 representative designs of d-c machines in the range of 100 to 7,000 horsepower. For purposes of comparison, a constant for the Wieseman formula was determined in the same manner as K_4 and K_5. It is apparent that the linear formula compares favorably with the other formulas and also has the advantage of simplicity. A size correction based on this linear relationship therefore is included in the minimum insulation resistance formula suggested by the authors.

Effect of Absolute Humidity

Insulation resistance of all rotating machines is affected by prevailing atmospheric moisture conditions. For this reason, machines built and tested during the winter months, in general, have appreciably higher insulation resistance values than identical machines built and tested during the summer months. This effect is, in general, greater on commutator type machines where large creepage areas from bare copper to ground exist. Study of the data reveals that insulation resistance of the armature circuit of d-c machines is affected by a combination of atmospheric moisture conditions at the time of test, and during the period of manufacture.

The insulation resistance measurements of the armature circuit windings discussed in this work were made shortly after the running test. Since condensation of atmospheric moisture on the insulation surfaces greatly distorts insulation resistance, all tests were made with insulation temperatures five to ten degrees above room conditions. Measurements were made at 500 volts d-c and one minute after voltage application.

The effect of extreme humidity conditions on the insulation resistance of a d-c armature is illustrated in Figure 2. This armature which was initially at equilibrium at 70 degrees Fahrenheit and 20 per cent relative humidity, was exposed to 90 per cent relative humidity at 100

degrees Fahrenheit for 17 days and then returned to the initial ambient conditions. A reduction to 1/13 of the initial resistance after making corrections for temperature was observed at the end of the first day. The temperature correction is based on a ten to one decrease in insulation resistance for a 50-degree-centigrade temperature increase. A further reduction of one half was observed for the succeeding 16 days. Upon returning to room conditions of humidity and temperature, a rapid recovery to approximately one half of the initial insulation resistance value was observed. It, therefore, is apparent that the insulation resistance of a d-c armature is affected greatly by the prevailing atmospheric conditions at the time of test.

To evaluate the effect of atmospheric moisture conditions on insulation resistance, correlations of absolute and relative humidity at time of test with insulation resistivity were attempted. The insulation resistance of the 1,100 machines was corrected for machine size by multiplying the measured values by the ratio of the effective slot area and insulation thickness. The units of insulation resistivity thus obtained were megohm-inches.

Comparison of insulation resistivity with relative humidity at time of test revealed no significant correlation. However, since it was evident from Figure 2 that humidity conditions at time of test should affect the insulation resistance significantly, a correlation between insulation resistivity and absolute humidity was attempted. Absolute humidity differs from relative humidity in that it is a quantitative measure of atmospheric moisture. Relative humidity merely expresses the ratio of actual atmospheric moisture to the maximum or saturation conditions for a given temperature. Since absolute humidity at saturation varies logarithmically with temperature, it is evident that relative humidity by itself is not a measure of atmospheric moisture.

For practical purposes vapor pressure in inches of mercury is a convenient measure of absolute humidity. A record of daily average and range of vapor pressures in the Pittsburgh district for the years 1941 through 1945 is shown in Figure 3.* These observations were made less than five miles from the place of manufacture and were assumed to represent ambient moisture conditions at the plant.

Figure 4 shows the correlation of median insulation resistivity with vapor pressure at the time of test (see the appendix). Based on this correlation, all armature insulation resistivities were corrected to a vapor pressure of 0.1 inch of mercury. Figure 5 shows a comparison of the uncorrected insulation resistance data, the same data corrected for machine size, and the same data again corrected for vapor pressure at the time of test. It is evident from Figure 5 that corrections for machine size and vapor pressure based on the foregoing correlation produce an improvement in the central tendency of the data.

Although the correlation shown in Figure 4 is based on vapor pressure at time of test, it actually includes the effect of vapor pressure during manufacture. This is true because, in most cases, the average vapor pressure conditions during manufacture and test are substantially the same. For purposes of applying a correction for vapor pressure at the time of test in a minimum insulation resistance formula, it is desirable to separate the effect of vapor pressure during manufacture from that at the time of test.

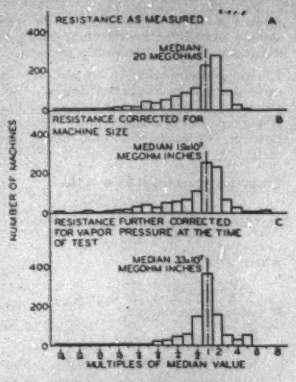

Figure 5. Comparison of insulation resistance frequency distributions before and after corrections—1,100 d-c machines

An examination was made of the insulation resistance of a large number of identical machines which were built at a rate of approximately 50 machines per month over a 15-month period. Table I shows the average insulation resistance of these armatures and the average monthly vapor pressures. If the following assumptions are made, it will be seen from column 3 of Table I that in most cases reasonable approximations for the effect of vapor pressure can be made:

1. Insulation resistance is inversely proportional to vapor pressure at time of test. Figure 2 shows a 13 to 1 initial reduction in insulation resistance for a 13 to 1 increase in vapor pressure.

2. Insulation resistance is inversely proportional to the vapor pressure at time of insulation varnish treatment. In the case of these machines, the time of varnish treatment is assumed to be two months prior to the month of test.

3. The over-all correction for manufacturing and test conditions is the product of the individual corrections for each influence. This assumption was made because it was found from inspection of the data of Table I that a correction of this sort correlated the observed data. Since only the creepage component of insulation resistance is affected by the vapor pressure at the time of test, the foregoing assumption implies that the principal effect of the humidity conditions during manufacture is on the creepage resistance.

Based on the preceding assumptions, a formula for correcting all the observed resistivities to constant vapor pressure conditions of 0.1 inch of mercury is as follows:

$$\text{Corrected resistivity} = \text{uncorrected resistivity} \times \frac{VP_1}{0.1} \times \frac{VP_2}{0.1}$$

where VP_1 and VP_2 are vapor pressures at the time of test and two months prior to the time of test, respectively. Column 3 of Table I indicates that, except for the months of October and November, monthly average resistivities corrected to constant vapor pressure conditions are approximately the same. Corrections, therefore, were made individually to the entire group of machines excluding those tested in October and November. Figure 6 gives a comparison of the frequency distribution of uncorrected and corrected data grouped according to multiples and

Table I. Correlation of Average Resistivity of 700 Identical D-C Armatures by Months, With Average Vapor Pressure at Month of Test and Two Months Prior to Test

Month	Avg Vapor Pressure, In. Hg	Uncorrected Avg Resistivities, Megohm-In. $\times 10^3$	Avg Resistivities Corrected to 0.1 In. Hg, Megohm-In. $\times 10^3$
January	0.14	2.9	6.9
February	0.13	2.5	4.8
March	0.15	3.8	8.0
April	0.20	2.7	7.0
May	0.37	1.3	7.2
June	0.57	0.56	6.5
July	0.54	0.58	11.5
August	0.53	0.36	7.8
September	0.36	0.43	8.3
October	0.35	1.7	32.6
November	0.17	2.9	17.7
December	0.13	3.0	9.0
January	0.14	3.5	8.3
February	0.14	3.1	5.2

* Data obtained from original records of the Pittsburgh Weather Bureau.

common fractions of the median value of resistivity. Figure 7 shows a frequency distribution of the corrected data grouped in the usual manner. As shown in Figures 6 and 7, the corrections significantly improve the normality of the observed data. Therefore, the assumptions of the relative effect on insulation resistance of the ambient humidity conditions during manufacture and test appear to be reasonable.

After a machine is in operation, the effect of moisture conditions at the time of varnish treatment would be expected to diminish, and in time the moisture content of the insulation is determined by the prevailing ambient and operating conditions. The real criterion of the moistureproof quality of machine insulation is not necessarily its moisture content, but rather the rate at which moisture is absorbed under given conditions. Under conditions of operation, accumulations of conducting particles on the exposed creepage surface may have a predominating influence on insulation resistance.

Suggested Minimum Formula

The principal requirement for an ideal minimum insulation resistance formula is a simple relationship between the factors which are known to affect the machine insulation resistance. These factors should be in terms of parameters which are known or are easily obtainable at the time of test.

1. *Variation of slot area*, for d-c machines in the range of 100 to 7,000 horsepower, has a maximum range of 100 to 1. A simple relationship between output and speed rating has been developed which makes an average correction with a 27 per cent dispersion. Since slot area varies to a certain extent independently of the output or speed rating, significantly closer correction does not appear possible.

2. *Variation of the exposed creepage surface of the armature* is approximately linearly related to the slot area of the armature so that any corrections made for slot area also will apply to this factor.

3. *Insulation wall thickness*, because of the limited voltage range of d-c machines, may be considered constant.

4. *Insulation temperature* for new d-c machines, where insulation resistance decreases by a factor of approximately ten, increases from 25 to 75 degrees centigrade. There is a relatively small amount of data on temperature-insulation resistance slopes of d-c machines. More data are needed to establish average values and probable dispersions for machines both when new and under operating conditions. In the meanwhile the effect of temperature is minimized best by consistently measuring the insulation resistance at approximately the same temperature. Five to ten degrees above ambient would be a convenient temperature. The possibility of moisture condensation then would be eliminated. If measurements are made at or close to room condition, temperature correction to 25 degrees centigrade, based on an assumed average slope, will introduce relatively small errors.

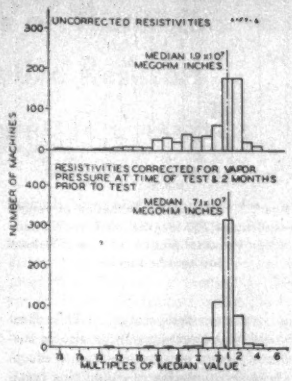
UNCORRECTED RESISTIVITIES
MEDIAN 1.9 x 10⁷ MEGOHM INCHES
RESISTIVITIES CORRECTED FOR VAPOR PRESSURE AT TIME OF TEST & 2 MONTHS PRIOR TO TEST
MEDIAN 7.1 x 10⁷ MEGOHM INCHES
NUMBER OF MACHINES
MULTIPLES OF MEDIAN VALUE

Figure 6. Comparison of insulation resistivity frequency distributions for 700 identical d-c machines before and after corrections for vapor pressure

5. *Absolute humidities immediately preceding the time of test* have been shown to affect the measured insulation resistance by as much as ten to one for variations normally encountered. A simple correction for this factor in terms of ambient temperature and relative humidity at the time of test is possible for this variable.

It might be pointed out here that insulation temperature, as well as absolute humidity, has a diminishing effect on insulation resistance of machines operated in service under conditions where an accumulation of conducting dirt is likely to be deposited on the exposed creepage surfaces.

Assuming that a simple formula which gives the average expected insulation resistance of a d-c armature is possible, the selection of a suitable minimum insulation resistance formula depends upon what this formula thus determined is intended to represent. If the criterion is the value which is safe for application of the proof voltage test, the level of insulation resistivity set by the formula, if moisture is considered to be the contaminating agent, should depend primarily on when the insulation contains a sufficient quantity of moisture to affect adversely the short-time dielectric strength of the insulation. It does not appear possible at the present time to state definitely what this resistivity should be. Exploratory tests for paper-backed sheet-form mica insulation indicate that the short-time breakdown does not begin to be affected significantly until the resistivity is of the order of 1/10,000 or less of the average new machine insulation resistivity. However, while moisture contamination is the principal source of low insulation resistance of new machines, it is not the only possible cause. Values of insulation resistance, which would be considered safe if the assumption could be made that the cause was uniformly distributed moisture, might not be safe if caused by some other factor such as defective or damaged insulation. It should be emphasized that a high value of insulation resistance is no guarantee of adequate dielectric strength for test or operation. Insulation defects are possible which do not affect the insulation resistance. At best, insulation resistance indicates the existence and approximate extent of contaminating influences which affect insulation leakage. It appears that the best procedure possible at the present time in the selection of a minimum formula is to reach some agreement as to

1. What the average resistivity of new machine insulation should be.

2. Some reasonable method by which the minimum insulation resistance shall be calculated from this average value. It should be recognized that the selection of this minimum has no logical basis except that it represents the best estimate possible at the present time.

Table II. Correction Factor for Absolute Humidity at Time of Test in Terms of Ambient Temperature and Relative Humidity

Ambient Temperature, Deg F	Correction Factor*
10	0.18
20	0.30
30	0.48
40	0.70
50	1.00
60	1.47
70	2.15
80	2.95
90	3.90
100	5.50

*f_a = factor × per cent relative humidity.

Based on the foregoing considerations, the following formula is suggested for minimum insulation resistance of new d-c armatures of ratings of 100 horsepower and higher. Essentially, the formula is an expression for the expected average armature circuit insulation resistance of a new machine after correction for machine size, insulation temperature at the time of test, and absolute humidity at the time of test. Since the ground insulation on

d-c machines is essentially the same in both cases, no distinction is made between class *A* and class *B* insulation. Also, for general purpose d-c machines, the voltage range is limited and insulation wall thickness is substantially unaffected by rated voltage. Therefore, the voltage factor has been omitted in the formula.

$$R_t = \frac{4{,}000}{\left(\frac{\text{horsepower}}{\text{revolutions per minute}} + 2\right) f_h}$$

R_t = minimum insulation resistance in megohms at 25 degrees centigrade

f_h = correction factor for absolute humidity at time of test (see Table II)

In addition to this formula, a 2-megohm minimum insulation resistance is suggested for armatures when the calculated value from the formula is below this value. In general, these armatures would be large and important, and there is the ever-present possibility that the low insulation resistance might not be caused by moisture contamination, but might be the result of other localized defects.

Summary and Conclusions

Analysis of insulation resistance data of 1,100 d-c machines in the range of 1,000 to 7,000 horsepower has resulted in the rationalization of the complex factors involved. Consideration and segregation of the principal factors which influence measured values of insulation resistance has enabled a better understanding of the relative effect of each. In addition to previously recognized factors such as material resistivity, insulation temperature, and machine size, the absolute humidity of the surrounding air has been found to affect significantly the insulation resistance of commutator type machines. The total effect of humidity on new machines at the factory has been shown to consist of

1. The effect of prevailing atmospheric humidity during insulation treatment.

2. The effect of atmospheric humidity at the time of test.

Prevailing atmospheric humidity during insulation treatment has only a transitory effect on the machine insulation resistance. Ultimate moisture concentration in machine insulation depends on service conditions. For commutator type machines, absolute humidity at the time of test is a test condition in the same sense as insulation temperature. This effect would be expected to apply also to machines under service conditions, except where accumulation of conducting particles on exposed creepage surfaces has a predominating influence.

The correlation of these various factors has resulted in the development of a simple linear insulation resistance formula which is offered for consideration by the industry.

$$R_t = \frac{4{,}000}{\left(\frac{\text{horsepower}}{\text{revolutions per minute}} + 2\right) f_h}$$

where

R_t = minimum insulation resistance at 25 degrees centigrade for new d-c machines over 100 horsepower

f_h = correction factor for absolute humidity at the time of test

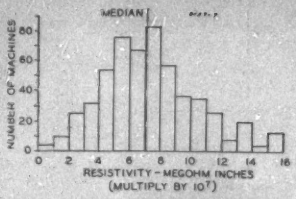

Figure 7. Frequency distribution of volume resistivity of 700 identical machines after correction for vapor pressure at time of test and two months prior to test

Appendix

Correlation of Computed Slot Area by Various Formulas and Actual Slot Area of Representative Designs

In the comparison of the correlation of the several formulas discussed in the text, use was made of graph paper having linear ordinate units and abscissa units arranged in an arithmetical probability scale. The ratio of computed to actual values for each formula was arranged in increasing order and expressed as a cumulative per cent of the total number of designs.

The interpretation of the ratio 1 corresponding to 50 per cent is that one half of the total number of designs have ratios of 1 or less. It is seen, therefore, that for the linear approximation the central 90 per cent of the distribution have ratios between 0.5 to 1.5. The scale of the abscissa is such that normal distributions plot as a straight line. The slope of this line is a measure of the dispersion and a smaller slope indicates smaller dispersion. Per cent dispersion, which for normal distributions is equal to $\frac{\text{standard deviation}}{\text{average}} \times 100$, may be obtained directly from the curve. The standard deviation includes approximately the central two thirds of the area distribution. Therefore, from the curve

per cent dispersion =

$$\frac{(R_{84.7} - R_{50}) \text{ or } (R_{50} - R_{15.9})}{R_{50}} \times 100$$

where $R_{84.7}$, R_{50}, and $R_{15.9}$ are the ratios for the corresponding cumulative percentages in the distribution.

Correlation of Insulation Resistivity and Vapor Pressure at Time of Test

In this correlation the individual values of resistivity were classified according to vapor pressure at the time of test. For each vapor pressure group the median value of insulation resistivity was obtained. The median is defined as the value of the central unit of a distribution. If a distribution contains 101 numbers arranged in order of increasing value, the value of number 51 is the median of the distribution. The median was used as a basis for comparison because it gives less weight to extreme values of a distribution than does the arithmetic average.

Preparation of Table II

Table II lists absolute humidity corrections to be applied in the minimum formula. Absolute humidity is a function of the product of ambient temperature and relative humidity. Since ambient temperature and relative humidities are usually either known or easily determined, the absolute humidity correction is expressed in these parameters.

The table was constructed by considering as unity an average vapor pressure of 0.35 inch of mercury. This corresponds to a temperature and relative humidity of 50 degrees Fahrenheit and 100 per cent. Relative corrections for other temperatures and humidities were obtained from psychometric tables and expressed in terms of the assumed average conditions. In the proposed minimum formula, the average resistivity used is that corresponding to 0.35 inch of mercury.

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Properties and Uses of Thermistors—Thermally Sensitive Resistors

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Synopsis: A new circuit element and control device, the thermistor, or thermally sensitive resistor, is made of solid semiconducting materials whose resistance decreases about four per cent per degree centigrade. The thermistor presents interesting opportunities to the designer and engineer in many fields of technology for accomplishing tasks more simply, economically, and better than with available devices. Part I discusses the conduction mechanism in semiconductors and the criteria for usefulness of circuit elements made from them. The fundamental physical properties of thermistors, their construction, their static and dynamic characteristics, and general principles of operation are treated. Part II of this paper deals with the applications of thermistors. These include: sensitive thermometers and temperature control elements, simple temperature compensators, ultrahigh frequency power meters, automatic gain controls for transmission systems, voltage regulators, speech volume limiters, compressors and expandors, gas pressure gauges and flowmeters, meters for thermal conductivity determination of liquids, and contactless time delay devices. Thermistors with short time constants have been used as sensitive bolometers, and show promise as simple, compact, audiofrequency oscillators, modulators, and amplifiers.

I—Properties of Thermistors

THERMISTORS, or *thermally sensitive resistors*, are devices made of solids whose electrical resistance varies rapidly with temperature. Even though they are only about 15 years old they already have found important and large scale uses in the telephone plant and in military equipments. Some of these uses are as time delay devices, protective devices, voltage regulators, regulators in carrier systems, speech volume limiters, test equipment for ultrahigh frequency power, and detecting elements for very small radiant power. In all these applications thermistors were chosen because they are simple, small, rugged, have a long life, and require little maintenance. Because of these and other desirable properties, thermistors promise to become new circuit elements which will be used extensively in the fields of communications, radio, electrical and thermal instrumentation, research in physics, chemistry and biology, and war technology. Specific types of uses which will be discussed in the second part of this paper include

1. Simple, sensitive, and fast responding thermometers, temperature compensators, and temperature control devices.
2. Special switching devices without moving contacts.
3. Regulators or volume limiters.
4. Pressure gauges, flowmeters, and simple meters for measuring thermal conductivity in liquids and gases.
5. Time delay and surge suppressors.
6. Special oscillators, modulators, and amplifiers for relatively low frequencies.

Before these uses are discussed in detail, it is desirable to present the physical principles which determine the properties of thermistors.

The question naturally arises: Why have devices of this kind come into use only recently? The answer is that thermistors are made of semiconductors and that the resistance of these can vary by factors up to a thousand or a million with surprisingly small amounts of certain impurities, with heat treatment, methods of making contact, and with the treatment during life or use. Consequently the potential application of semiconductors was discouraged by experiences such as the following: two or more units made by what appeared to be the same process would show large variations in their properties. Even the same unit might change its resistance by factors of two to ten by exposure to moderate temperatures or to the passage of current. Before semiconductors could be considered seriously in industrial applications, it was necessary to devote a large amount of research and development effort to a study of the nature of the conductivity in semiconductors, and of the effect of impurities and heat treatment on this conductivity, and to methods of making reliable and permanent contacts to semiconductors. Even though Faraday discovered that the resistance of silver sulphide changed rapidly with temperature, and even though thousands of other semiconductors have been found to have large negative temperature coefficients of resistance, it has taken about a century of effort in physics and chemistry to give the engineering profession this new tool which may have an influence similar to that of the vacuum tube, and may replace vacuum tubes in many instances.

If thermistors are to be generally useful in industry:

1. It should be possible to reproduce units having the same characteristics.
2. It should be possible to maintain constant characteristics during use, the contact should be permanent, and the unit should be chemically inert.
3. The units should be mechanically rugged.
4. The technique should be such that the material can be formed into various shapes and sizes.
5. It should be possible to cover a wide range of resistance, temperature coefficient, and power dissipation.

Thermistors might be made by any method by which a semiconductor could

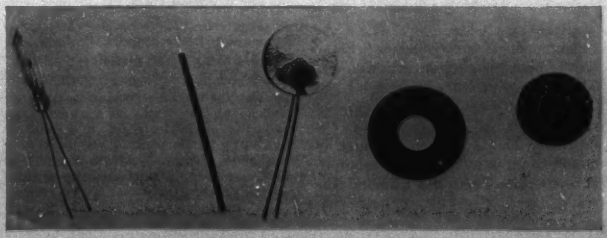

Figure 1. Thermistors made in the form of a bead, rod, disk, washer, and flakes (left to right)

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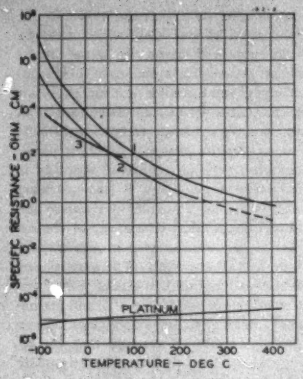


Figure 2. Logarithm of specific resistance versus temperature for three thermistor materials as compared with platinum

be shaped to definite dimensions, and contacts applied. These methods include

1. Melting the semiconductor, cooling, solidifying, cutting to size and shape.

2. Evaporation.

3. Heating compressed powders of semiconductors to a temperature at which they sinter into a strong compact mass, and firing on metal powder contacts.

Although all three processes have been used, the third method has been found to be useful most generally for mass production. This method is similar to that employed in ceramics or in powder metallurgy. At the sintering temperatures, the powders recrystallize and the dimensions shrink by controlled amounts. The powder process makes it possible to mix two or more semiconducting oxides in varying proportions, and obtain a homogeneous and uniform solid. It is thus possible to cover a considerable range of specific resistance and temperature coefficient of resistance with the same system of oxides. By means of the powder process, it is possible to make thermistors of a great variety of shapes and sizes to cover a large range of resistances and power handling capacities.

Figure 1 shows thermistors made in the form of beads, rods, disks, washers, and flakes. Beads are made by stringing two platinum alloy wires parallel to each other with a spacing of five to ten times the wire diameter. A mass of a slurry of mixed oxides is applied to the wires. Surface tension draws this mass into the form of a bead. From 10 to 20 such beads are evenly spaced along the wires. The beads are allowed to dry, and are heated slightly until they have sufficient strength so that the string can be handled. They then are passed through the sintering furnace. The oxides shrink onto the platinum alloy wires and make an intimate and permanent electrical contact. The wires then are cut to separate the individual beads. The diameters of the beads range from 0.015 to 0.15 centimeter with wire diameter ranging from 0.0025 to 0.015 centimeter.

Rod thermistors are made by mixing the oxides with an organic binder and solvent, extruding the mixture through a die, drying, cutting to length, heating to drive out the binder, and sintering at a high temperature. Contacts are applied by coating the ends with silver, gold, or platinum paste such as is used in the ceramic art, and heating or curing the paste at a suitable temperature. The diameter of the rods ordinarily can be varied from 0.080 to 0.64 centimeter. The length can vary from 0.15 to 5 centimeters.

Disks and washers are made in a similar way by pressing the bonded powders in a die. Possible disk diameters are 0.15 to 3 or 5 centimeters, thicknesses from 0.080 to 0.64 centimeter.

Flakes are made by mixing the oxides with a suitable binder and solvent to a creamy consistency, spreading a film on a smooth glass surface, allowing the film to dry, removing the film, cutting it into flakes of the desired size and shape, and firing the flakes at the sintering temperatures on smooth ceramic surfaces. Contacts are applied as described above. Possible dimensions are: thickness, 0.001 to 0.004 centimeter; length, 0.1 to 1.0 centimeter; width, 0.02 to 0.1 centimeter.

In any of these forms, lead wires can be attached to the contacts by soldering or by firing heavy metal pastes. The dimensional limits given above are those which have been found to be readily attainable.

In the design of a thermistor for a specific application, the following characteristics should be considered:

1. Mechanical dimensions including those of the supports.

2. The material from which it is made and its properties. These include the specific resistance and how it varies with temperature, the specific heat, density, and expansion coefficient.

3. The dissipation constant and power sensitivity. The dissipation constant is the watts that are dissipated in the thermistor, divided by its temperature rise in degrees centigrade above its surroundings. The power sensitivity is the watts dissipated to reduce the resistance by one per cent. These constants are determined by the area and nature of the surface, the surrounding medium, and the thermal conductivity of the supports.

4. The heat capacity, which is determined by specific heat, dimensions, and density.

5. The time constant. This determines how rapidly the thermistor will heat or cool. If a thermistor is heated above its surroundings and then allowed to cool, its temperature will decrease rapidly at first, and then more slowly until it finally reaches ambient temperature. The time constant is the time required for the temperature to fall 63 per cent of the way toward ambient temperature. The time constant in seconds is equal to the heat capacity in joules per degree centigrade, divided by the dissipation constant in watts per degree centigrade.

6. The maximum permissible power that can be dissipated consistent with good stability and long life, for continuous operation, and for surges. This can be computed from the dissipation constant and the maximum permissible temperature rise. This and the resistance-temperature relation determine the maximum decrease in resistance.

Properties of Semiconductors

As most thermistors are made of semiconductors, it is important to discuss the properties of the latter. A semiconductor may be defined as a substance whose electrical conductivity at, or near, room temperature is much less than that of typical metals, but much greater than that of typical insulators. While no sharp boundaries exist between these classes of conductors, one might say that semiconductors have specific resistances at room

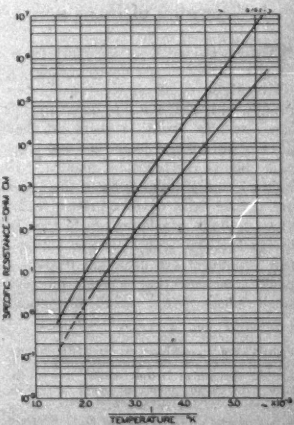


Figure 3. Logarithm of the specific resistance of two thermistor materials as a function of inverse absolute temperature

See equation 1

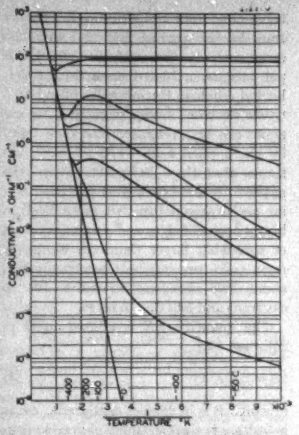


Figure 4. Logarithm of the conductivity of various specimens of silicon as a function of inverse absolute temperature

The conductivity increases with the amount of impurity

temperature from 0.1 to 10^9 ohm-centimeters. Semiconductors usually have high negative temperature coefficients of resistance. As the temperature is increased from 0 degrees centigrade to 300 degrees centigrade, the resistance may decrease by a factor of a thousand. Over this same temperature range the resistance of a typical metal, such as platinum, will increase by a factor of two. Figure 2 shows how the logarithm of the specific resistance, ρ, varies with temperature, T, in degrees centigrade for three typical semiconductors and for platinum. Curves 1 and 2 are for "material 1" and "material 2" which have been used extensively to date. "Material 1" is composed of manganese and nickel oxides. "Material 2" is composed of oxides of manganese, nickel, and cobalt. The dashed part of curve 2 covers a region in which the resistance-temperature relation is not known as accurately as it is at lower temperatures. Curve 3 is an experimental curve for a mixture of iron and zinc oxides in the proportions to form zinc ferrite. From Figure 2 it is obvious that neither the resistance R nor $\log R$ varies linearly with T.

Figure 3 shows plots of $\log \rho$ versus $1/T$ for "material 1" and "material 2". These do form approximate straight lines. Hence:

$$\rho = \rho_\infty e^{B/T} \text{ or } \rho = \rho_0 \epsilon^{(B/T - B/T_0)} \qquad (1)$$

where T = temperature in degrees Kelvin, $\rho_\infty = \rho$ when $T = \infty$ or $1/T = 0$, $\rho_0 = \rho$ when $T = T_0$, ϵ = Naperian base = 2.718, and B is a constant equal to 2.303 times the slope of the straight lines in Figure 3. The dimensions of B are degrees Kelvin or degrees centigrade. B plays the same role in equation 1 as does the work function in Richardson's equation for thermionic emission. For material 1, B = 3,920 degrees centigrade. This corresponds to an electron energy of 3,920/11,600 or 0.34 volt.

While the curves in Figure 3 are approximately straight, a more careful investigation shows that the slope increases linearly as the temperature increases. From this it follows that a more precise expression for ρ is:

$$\rho = A T^{-c} \epsilon^{D/T}$$

or

$$\log \rho = \log A - c \log T + D/2.303T \qquad (2)$$

The constant c is a small positive or negative number or zero. For "material 1", $\log A = 5.563$, $c = 2.73$, and $D = 3{,}100$. For a particular form of "material 2", $\log A = 11.514$, $c = 4.83$, and $D = 2{,}064$.

If we define temperature coefficient of resistance, α, by the equation

$$\alpha = (1/R)(dR/dT) \qquad (3)$$

it follows from equation 1 that

$$\alpha = -B/T^2 \qquad (4)$$

For "material 1", and T = 300 degrees Kelvin, $\alpha = -3{,}920/90{,}000 = -0.044$. For platinum, $\alpha = +0.0037$, or roughly ten times smaller than for semiconductors, and of the opposite sign. From equation 2 it follows that

$$\alpha = -(D/T^2) - (c/T) \qquad (5)$$

From equation 3 it follows that

$$\alpha = (1/2.303)\ (d \log R/dT) \qquad (6)$$

For a discussion of the nature of the conductivity in semiconductors, it is simpler and more convenient to consider the conductivity, σ, rather than the resistivity, ρ.

$$\sigma = 1/\rho \text{ and } \log \sigma = -\log \rho \qquad (7)$$

The characteristics of semiconductors are brought out more clearly if the conductivity or its logarithm are plotted as a function of $1/T$ over a wide temperature range. Figure 4 is such a plot for a number of silicon samples containing increasing amounts of impurity. At high temperatures, all the samples have nearly the same conductivity. This is called the intrinsic conductivity because it seems to be an intrinsic property of silicon. At low temperatures the conductivity of different samples varies by large factors. In this region silicon is said to be an impurity semiconductor. For extremely pure silicon, only intrinsic conductivity is present and the resistivity obeys equation 1. As the concentration of a particular impurity increases, the conductivity increases, and the impurity conductivity predominates to higher temperatures. Some impurities are much more effective in increasing the conductivity than others. One hundred parts per million of some impurities may increase the conductivity of pure silicon at room temperature by a factor of 10^7. Other impurities may be present in 10,000 parts per million and have a small effect on the conductivity. Two samples may contain the same concentration of an impurity and still differ greatly in their low temperature conductivity. If the impurity is in solid solution, that is, atomically dispersed, the effect is great; if the impurity is segregated in atomically large particles, the effect is small. Since heat treatments affect the dispersion of impurities in solids, the conductivity of semiconductors frequently may be altered radically by heat treatment. Some other semiconductors are not affected greatly by heat treatment.

The impurity need not be a foreign element; in the case of oxides or sulphides, it can be an excess or a deficiency of oxygen or sulphur from the exact

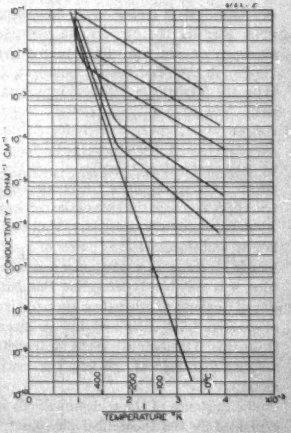


Figure 5. Logarithm of the conductivity of various specimens of cuprous oxide as a function of inverse absolute temperature

The conductivity increases with the amount of excess oxygen above the stoichiometric value in Cu_2O

Data from reference 1

stoichiometric relation. This excess or deficiency can be brought about by heat treatment. Figure 5 shows how the conductivity depends on temperature for a number of samples of cuprous oxide, Cu_2O, heat-treated in such a way as to result in varying amounts of excess oxygen from zero to about one per cent.[1] The greater the amount of excess oxygen, the greater is the conductivity in the low temperature range. At high temperatures, all samples have about the same conductivity.

Semiconductors can be classified on the basis of the carriers of the current into ionic, electronic, and mixed conductors. Chlorides such as NaCl and some sulphides are ionic semiconductors; other sulphides and a few oxides, such as uranium oxide, are mixed semiconductors; electronic semiconductors include most oxides such as Mn_3O_4, Fe_2O_3, NiO, carbides such as silicon carbide, and elements such as boron, silicon, germanium, and tellurium. In ionic and mixed conductors, ions are transported through the solid. This changes the density of carriers in various regions, and thus changes the conductivity. Because this is undesirable, they rarely are used in making thermistors, and hence we will concentrate our interest on electronic semiconductors.

The theoretical and experimental physicists have established that there are two types of electronic semiconductors which can be called *N* and *P* type, depending upon whether the carriers are negative electrons or are equivalent to positive "holes" in the filled energy band. In *N* type, the carriers are deflected by a magnetic field as negatively charged particles would be, and conversely for *P* type. The direction of deflections is ascertained by measurement of the sign of the Hall effect. The direction of the thermoelectric effect also fixes the sign of the carriers. By determining the resistivity, Hall coefficient, and thermoelectric power of a particular specimen at a particular temperature, it is possible to determine the density of carriers, whether they are negative or positive, and their mobility or mean free path. The mobility is the mean drift velocity in a field of one volt per centimeter.

The existence of these classifications is explained by the theoretical physicist[1-2] in terms of the diagrams in Figure 6. In an intrinsic semiconductor, at low temperatures the valence electrons completely fill all the allowable energy states. According to the exclusion principle, only one electron can occupy a particular energy state in any system. In semiconductors and insulators there exists a region of energy values, just above the allowed band, which are not allowed. The height of this unallowed band is expressed in equivalent electron volts, ΔE. Above this unallowed band there exists an allowed band, but at low temperatures there are no electrons in this band. When a field is applied across such a semiconductor, no electron can be accelerated, because if it were accelerated, its energy would be increased to an energy state which is either filled or unallowed. As the temperature is raised, some electrons acquire sufficient energy to be raised across the unallowed band into the upper allowed band. These electrons can be accelerated into a slightly higher energy state by the applied field and thus can carry current. For every electron that is put into an activated state there is left behind a hole in the normally filled band. Other electrons having slightly lower energies can be accelerated into these holes by the applied field. The physicist has shown that these holes act toward the applied field as if they were particles having a charge equal to that of an electron but of opposite sign, and a mass equal to, or somewhat larger than, the electronic mass. In an intrinsic semiconductor, about half the conductivity is due to electrons and half due to holes.

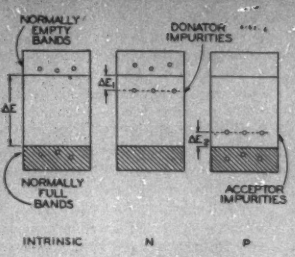


Figure 6. Schematic energy level diagrams illustrating intrinsic, *N*, and *P* types of semiconductors

The quantity ΔE is related to B in equation 1 by

$$2B = (\Delta E)e/k \qquad (8)$$

in which B is in degrees centigrade, ΔE is in volts, e is the electronic charge in coulombs, k is Boltzmann's constant in joules per degree centigrade. The value of e/k is 11,600 so that

$$\Delta E = B/5{,}800 \qquad (8a)$$

The difference between metals, semiconductors, and insulators results from the value of ΔE. For metals ΔE is zero or very small. For semiconductors ΔE is greater than about 0.1 volt, but less than about 1.5 volts. For insulators ΔE is greater than about 1.5 volts.

Some impurities with positive valencies which may be present in the semiconductor may have energy states such that ΔE_1 volts equivalent energy can raise the valence electron of the impurity atom into the allowed conduction band. See Figure 6. The electron now can take part in conduction; the donator impurity is a positive ion which usually is bound to a particular location and can take no part in the conductivity. These are excess or *N* type conductors. The conductivity depends on the density of donators, ΔE_1, and T.

Similarly, some other impurity with negative valencies may have an energy state ΔE_2 volts above the top of the filled band. At room temperature or higher, an electron in the filled band may be raised in energy and accepted by the impurity, which then becomes a negative ion and usually is immobile. However, the hole which results can take part in the conductivity.

In all cases represented in Figure 6, an electron occupying a higher energy level than a positive ion or a hole, has a certain probability that in any short interval of time it will drop into a lower energy state. However, during this same time interval there will be electrons which will be

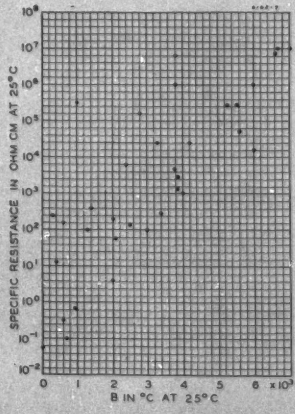


Figure 7. Logarithm of the resistivity of various semiconducting materials as a function of *B* in equation 1

The quantity, *B*, is proportional to the temperature coefficient of resistance as given in equation 4

raised to a higher energy level by thermal agitation. When the number of electrons per second which are being elevated is equal to the number which are descending in energy, equilibrium prevails. The conductivity, σ, is then

$$\sigma = Ne v_1 + Pe v_2 \qquad (9)$$

where N and P are the concentrations of electrons and holes respectively, e is the charge on the electron, v_1 and v_2 are the mobilities of electrons and holes respectively.

This explains the following experimental facts which otherwise are difficult to interpret:

1. *N*-type oxides, such as ZnO, when heated in a neutral or slightly reducing atmosphere become good conductors, presumably because they contain excess zinc which can donate electrons. If they then are heated in atmospheres which are increasingly more oxidizing, their conductivity decreases until eventually they are intrinsic semiconductors or insulators.

2. *P*-type oxides, such as NiO, when heat-treated in strongly oxidizing atmospheres are good conductors. Very likely they contain oxygen in excess of the stoichiometric relation and this oxygen accepts additional electrons. When these are heated in less oxidizing or neutral atmospheres they become poorer conductors, semiconductors, or insulators.

3. When a *P*-type oxide is sintered with another *P*-type oxide, the conductivity increases; similarly for two *N*-type oxides. But when a *P* type is added to an *N* type the conductivity decreases.

4. If a metal forms several oxides, the one in which the metal exerts its highest valence is *N* type, while the one in which it exerts its lowest valence will be *P* type.[8]

For several reasons it is desirable to survey the whole field of semiconductors for resistivity and temperature coefficient. One way in which this might be done is to draw a line in Figure 3 for each specimen. Before long, such a figure would consist of such a maze of intersecting lines that it would be difficult to single out and follow any one line. The information can be condensed by plotting log ρ_0 versus B in equation 1 for each specimen.[6] The most important characteristics of a specimen thus are represented by a single point and many more specimens can be surveyed in a single diagram. Figure 7 shows such a plot for a large number of semiconductors investigated at these laboratories or reported in the literature. Values for ρ_0 and B are given for T = 25 degrees centigrade. The points form a sort of "milky way." Semiconductors having a high ρ_0 are likely to have a high value of B and vice versa. If a series of semiconductors has points in Figure 7 which fall on a straight line with a slope of 1/2.3 T_0, they have a common intercept in Figure 3 for $(1/T) = 0$.

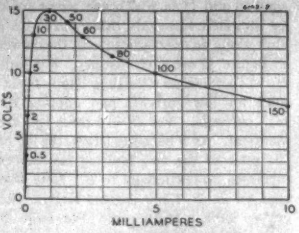


Figure 8. Static voltage–current curve for a typical thermistor

The numbers on the curve are the degrees centigrade rise in temperature above ambient temperature

Physical Properties of Thermistors

One of the most interesting and useful properties of a thermistor is the way in which the voltage, V, across it changes as the current, I, through it increases. Figure 8 shows this relationship for a 0.061-centimeter diameter bead of "material 1" suspended in air. Each time the current is changed, sufficient time is allowed for the voltage to attain a new steady value. Hence this curve is called the steady state curve. For sufficiently small currents, the power dissipated is too small to appreciably heat the thermistor, and Ohm's law is followed. However, as the current assumes larger values, the power dissipated increases, the temperature rises above ambient temperature, the resistance decreases, and hence the voltage is less than it would have been had the resistance remained constant. At some current, I_m, the voltage attains a maximum or peak value, V_m. Beyond this point, as the current increases the voltage decreases, and the thermistor is said to have a negative resistance whose value is dV/dI. The numbers on the curve give the rise in temperature above ambient temperature in degrees centigrade.

Because currents and voltages for different thermistors cover such a large range of values, it has been found convenient to plot log V versus log I. Figure 9 shows such a plot for the same data as in Figure 8. For various points on the curve, the temperature rise above ambient temperature is given. In a log log plot, a line with a slope of 45 degrees represents a constant resistance, and a line with a slope of −45 degrees represents constant power.

For a particular thermistor, the position of the log V versus log I plot is shifted, as shown in Figure 10, by changing the dissipation constant C. This can be done by changing the air pressure surrounding the bead, changing the medium, or changing the degree of thermal coupling between the thermistor and its surroundings. The value of C for a particular thermistor in given surroundings readily can be determined from the V versus I curve in either Figures 8 or 9. For each point, V/I is the resistance, while V times I is W, the watts dissipated. The resistance data are converted to temperature from R versus T, given by equation 2. A plot is then made of W versus T. For thermistors in which most of the heat is conducted away, W will increase linearly with T, so that C is constant. For thermistors suspended by fine wires in a vacuum, W will increase more rapidly than proportional to T, and C will increase with T. For thermistors of ordinary size and shape, in still air, C/area is equal to from 1 to 40 milliwatts per degree centigrade per square centimeter, depending upon the size and shape factor.

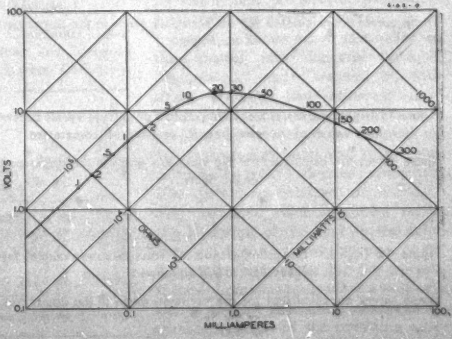


Figure 9. Logarithmic plot of static voltage–current curve for the same data as in Figure 8

The diagonal lines give the values of resistance and power

The user of a thermistor may want to know how many watts can be dissipated before the resistance decreases by one per cent. This may be called the power sensitivity. It is equal to $C/(\alpha \times 100)$ or about one to ten milliwatts per square centimeter in still air. Both C and the power sensitivity increase with air velocity. The dependence of C on gas pressure and velocity is the basis of the use of thermistors as manometers, and as anemometers or flowmeters. Note that in Figure 10 one curve can be superposed on any other by a shift along a constant resistance line.

Figure 11 shows a family of log V versus log I curves for various values of R_o while B, C, and T_a are kept constant. This can be brought about by changing the length, width, and thickness to vary R_o while the surface area is kept constant. If the resistance had been changed by changing the ambient temperature, T_a, the resulting curves would not appear very different from those shown. Note that one curve can be superposed on any other curve by a shift along a constant power line.

Figure 12 shows a family of log V versus log I curves for eight different values of B while C, R_o, and T_a are kept constant. In contrast to the curves in Figures 10 and 11 in which any curve could be obtained from any other curve by a shift along an appropriate axis, the curves in Figure 12 are each distinct. For each curve there exists a limiting ohmic resistance for low currents and another for high currents. For $B = 0$ these two are identical. As B becomes larger, the log of the ratio of the two limiting resistances increases proportionally to B. Note also that for $B > 1{,}200$ degrees Kelvin, the curves have a maximum. For large B values this maximum occurs at low powers and hence at low values of $T - T_a$. This follows as $W = C(T - T_a)$. As B decreases, V_m occurs at increasingly higher powers or temperatures. For $B < 1{,}200$ degrees Kelvin no maximum exists.

The curves in Figures 10 to 12 have been drawn for the ideal case in which the resistance in series with the thermistor is zero, and in which no temperature limitations have been considered. In any actual case there always is some unavoidable small resistance, such as that of the leads, in series with the thermistor, and hence the parts of the curves corresponding to low resistances may not be observable. Also, at high powers the temperature may attain such values that something in the thermistor structure will go to pieces, thus limiting the range of observation. These unobservable ranges have been indicated by dashed lines in Figure 12. The exact location of the dashed portions will of course depend on how a completed thermistor is constructed. In setting these limits we also have considered temperature limitations beyond which aging effects might become too great.

The curves in Figures 9 to 12 have been computed on the basis of the following equations:

$$R = R_o e^{(B/T) - (B/T_a)} = V/I \tag{10}$$

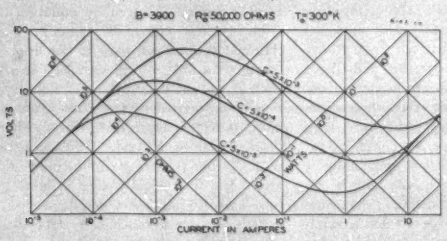
$$W = C(T - T_a) = VI \tag{11}$$

For these curves the constants R_o, T_a, B, and C are specified. The values of temperature, T_m, power, W_m, resistance, R_m, voltage, V_m, and current, I_m, that prevail at the maximum in the voltage current curve are given by the following equations in which T_m is chosen as the independent parameter. By differentiating equations 10 and 11 with respect to I, putting the derivatives equal to zero, one obtains

$$T_m^2 = B(T_m - T_a) \tag{12}$$

whose solution is

$$T_m = (B/2)(1 \mp \sqrt{1 - 4T_a/B}) \tag{13}$$



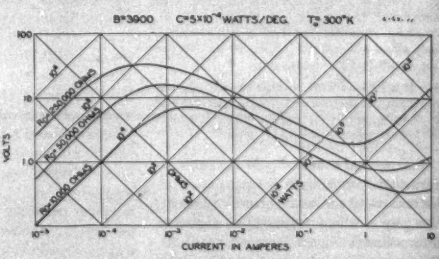


Figure 10 (above). Logarithmic plots of voltage versus current for three values of the dissipation constant C

These curves are calculated for the constants given in the upper part of the figure

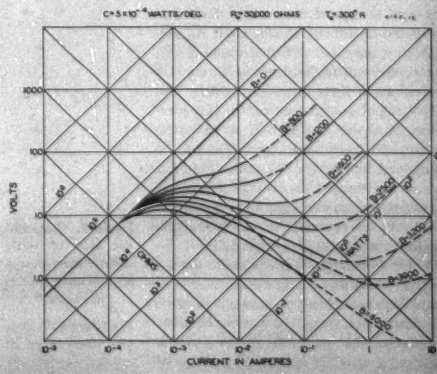


Figure 11 (right, above). Logarithmic plots of voltage versus current for three values of the resistance, R_o, at ambient temperature

These curves are calculated for the constants given in the upper part of the figure

Figure 12 (right). Logarithmic plots of voltage versus current for eight values of B in equation 1

These curves are calculated for the constants given in the upper part of the figure

The minus sign pertains to the maximum in Figures 10 to 12 while the plus sign pertains to the minimum. Note that T_m depends only on B and T_a, and not on R, R_a, or C. From equations 4, 10, and 11 it follows that

$$-\alpha_m(T_m - T_a) = 1 \tag{14}$$

$$W_m = C(T_m - T_a) \tag{15}$$

$$R_m = R_a\epsilon^{-T_m/T_0} \doteq R_a\epsilon^{-1}[1-(T_m-T_a)/T_a + (1/2)\{(T_m-T_a/T_a)\}^2 - \ldots] \tag{16}$$

$$V_m = [CR_a(T_m-T_a)(\epsilon^{-T_m/T_0})]^{1/2} = \left\{CR_a(T_m-T_a)\epsilon^{-1}[1-(T_m-T_a)/T_a + (1/2)\{(T_m-T_a)/T_a\}^2 - \ldots]\right\}^{1/2} \tag{17}$$

$$I_m = [(C/R_a)(T_m-T_a)\epsilon^{T_m/T_0}]^{1/2} = \left\{(C/R_a)(T_m-T_a)\epsilon[1+(T_m-T_a)/T_a + (1/2)\{(T_m-T_a)/T_a\}^2 + \ldots]\right\}^{1/2} \tag{18}$$

Thus far the presentation has been limited to steady state conditions, in which the power supplied to the thermistor is equal to the power dissipated by it, and the temperature remains constant. In many cases, however, it is important to consider transient conditions when the temperature, and any quantities which are functions of temperature, vary with time. A simple case which will illustrate the concepts and constants involved in such problems is as follows: A massive thermistor is heated to about 150 to 200 degrees centigrade by operating it well beyond its peak. At time $t = 0$, the circuit is switched over to a constant current having a value so small that I^2R always is negligibly small. The voltage across the thermistor then is followed as a function of time. From this, the resistance and temperature are computed. Figure 13 shows a plot of log $(T - T_a)$ versus t for a rod thermistor of "material 1", about 1.2 centimeters long, 0.30 centimeter in diameter, and weighing 0.380 gram. In any time interval Δt, there are $C(T - T_a)\Delta t$ joules being dissipated. As a result the temperature will decrease by ΔT given by

$$-H\Delta T = C(T - T_a)\Delta t$$

or

$$(T - T_a) = -(H/C)(\Delta T/\Delta t) \tag{19}$$

where H = heat capacity in joules per degree centigrade. The solution of this equation is

$$(T - T_a) = (T_0 - T_a)\epsilon^{-t/\tau} \tag{20}$$

in which $T_0 = T$ when $t = 0$, and

$$\tau = H/C \tag{21}$$

where τ is in seconds. It commonly is called the time constant. From equation 20 it follows that a plot of log $(T - T_a)$ versus t should yield a straight line whose slope $= -1/2.303\ \tau$. If H and C vary slightly with temperature, then τ will vary slightly with T and t. The line will not be perfectly straight, but its slope at any t or $(T - T_a)$ will yield the appropriate τ or H/C for that T. As previously described, C can be determined from a plot of watts dissipated versus T. For this thermistor this curve became steeper at the higher temperatures so that C increased for higher temperatures. Table I summarizes the values of C, τ, and H at various T.

When a thermistor is heated by passing current through it, conditions are involved somewhat more since the I^2R power will be a function of time. At any time in the heating cycle, the heat power liberated will be equal to the watts dissipated, or $C(T - T_a)$ plus watts required to raise the temperature, or HdT/dt. The heat power liberated will depend on the circuit conditions. In a circuit like that shown in the upper corner of Figure 14, the current varies with time, as shown by the six curves for six values of the battery voltage E. If a relay in the circuit operates when the current reaches a definite value, a considerable range of time delays can be achieved. This family of curves will be modified by changes in ambient temperature and where rather precise time delays are required, the ambient temperature must be controlled or compensated.

Since thermistors cover a wide range in size, shape, and heat conductivity of surrounding media, large variations in H, C, and τ can be produced. The time constant can be varied from about one millisecond to about ten minutes or a millionfold.

One very important property of a thermistor is its aging characteristic, or how

Table I. Values of C, τ, H as Functions of T for a Thermistor of "Material 1"

Thermistor About 1.2 Centimeters Long, 0.30 Centimeter in Diameter, and Weighing 0.380 Gram. $T_a = 24$ Degrees Centigrade

T, Deg C	C, Watts Per Deg C	τ, Sec	H, Joules Per Deg C	h, Joules Per Gram Per Deg C
44	0.0037	76	0.28	0.75
64	0.0037	74	0.27	0.72
84	0.0038	71	0.27	0.71
104	0.0037	69	0.26	0.68
124	0.0038	68	0.26	0.67
144	0.0038	67	0.26	0.67
164	0.0039	67	0.26	0.69
184	0.0041	66	0.27	0.71
204	0.0042	66	0.28	0.73

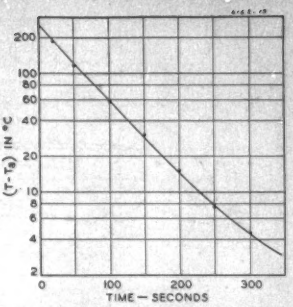


Figure 13. Cooling characteristic of a massive thermistor—logarithm of temperature above ambient versus time

constant the resistance at a given temperature stays with use. To obtain a stable thermistor it is necessary to

1. Select only semiconductors which are pure electronic conductors.
2. Select those which do not change chemically when exposed to the atmosphere at elevated temperatures.
3. Select one which is not sensitive to impurities likely to be encountered in manufacture or in use.
4. Treat it so that the degree of dispersion of the critical impurities is in equilibrium, or else that the approach to equilibrium is very slow at operating temperatures.
5. Make a contact which is intimate, sticks tenaciously, has an expansion coefficient compatible with the semiconductor, and is durable in the atmospheres to which it will be exposed.
6. In some cases, enclose the thermistor in a thin coat of glass or material impervious to gases and liquids, the coat having a suitable expansion coefficient.
7. Preage the unit for several days or weeks at a temperature somewhat higher than that to which it will be subjected.

By taking these precautions, remarkably good stabilities can be obtained.

Figure 15 shows aging data taken on three-quarter inch diameter disks of "material 1" and "material 2" with silver contacts and soldered leads. These disks were measured soon after production, were aged in an oven at 105 degrees centigrade, and were tested periodically at 24 degrees centigrade. The percentage change in resistance over its initial value is plotted versus the logarithm of the time in the aging oven. It is to be noted that most of the aging takes place in the first day or week. If these disks were preaged for a week or a month and the subsequent change in resistance referred to the resistance after

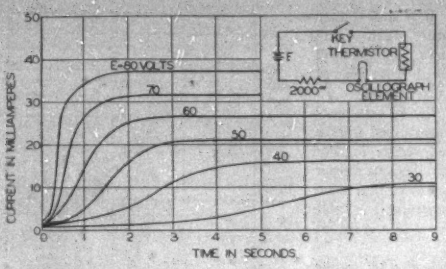


Figure 14. Current versus time curves for six values of the battery voltage in the circuit shown in the insert

preaging, they would age only about 0.2 per cent in one year. In a thermistor thermometer, this change in resistance would correspond to a temperature change of 0.05 degree centigrade. Thermistors mounted in an evacuated tube or coated with a thin layer of glass, age even less than those shown in the figure. For some applications such high stability is not essential, and it is not necessary to give the thermistors special treatment.

Thermistors have been used at higher temperatures with satisfactory aging characteristics. Extruded rods of "material 1" have been tested for stability by treating them for two months at a temperature of 300 degrees centigrade. Typical units aged from 0.5 to 1.5 per cent of their initial resistance. Similar thermistors have been exposed alternately to temperatures of 300 degrees centigrade and −75 degrees centigrade for a total of 700 temperature cycles, each lasting one-half hour. The resistance of typical units changed by less than one per cent.

In some applications of thermistors, very small changes in temperature produce small changes in potential across the thermistor, which are amplified then in high gain amplifiers. If at the same time the resistance is fluctuating randomly by as little as one part in a million, the potential across the thermistor also will fluctuate by a magnitude which will be directly proportional to the current. This fluctuating potential is called noise, and as it depends on the current, it is called current noise. In order to obtain the best signal to noise ratio, it is necessary that the current noise at operating conditions be less than Johnson or thermal noise.[7,8] To make noise-free units it is necessary to pay particular attention to the raw materials, the degree of sintering, the grain size, the method of making contact, and any steps in the process which might result in minute surface cracks or fissures.

All the thermistors discussed thus far either were heated directly by the current passing through them or by changes in ambient temperature. In indirectly heated thermistors, the temperature and resistance of the thermistor are controlled primarily by the power fed into a heater thermally coupled to it. One such form might consist of a 0.038-centimeter diameter bead of "material 2" embedded in a small cylinder of glass about 0.38 centimeter long and 0.076 centimeter in diameter. A small nichrome heater coil having a resistance of 100 ohms is wound on the glass and is fused onto it with more glass. Figure 16 shows a plot of log V versus log I for the bead element at various currents through the heater. In this way the bead resistance can be changed from 3,000 ohms to about 10 ohms. Indirectly heated thermistors ordinarily are used where the controlled circuit must be isolated electrically from the actuating circuit, and where the power from the latter must be fed into a constant resistance heater.

II—Uses of Thermistors

The thermistor, or thermally sensitive resistor, probably has excited more interest as a major electric circuit element than any other except the vacuum tube in the last decade. Its extreme versatility, small size, and ruggedness were responsible for its introduction in great numbers into communications circuits within five years after its first application in this field. The next five year period spanned the war, and saw thermistors widely used in additional important applications. The more important of these uses ranged from time delays and temperature controls to feed-back amplifier automatic gain controls, speech volume limiters, and superhigh frequency power meters. It is surprising that such versatility can result from a temperature-dependent resistance characteristic alone. However, this effect produces a very useful nonlinear volt-ampere relationship. This, together with the ability to produce the sensitive element in a wide variety of shapes and sizes results in applications in diverse fields. The variables of design are many and interrelated, including electrical, thermal, and mechanical dimensions.

The more important uses of thermistors as indication, control, and circuit elements will be discussed, grouping the uses as they fall under the primary characteristics: resistance-temperature, volt-ampere, and current-time or dynamic relations.

Resistance–Temperature Relations

It has been pointed out in part I that the temperature coefficient of electrical resistance of thermistors is negative and several times that of the ordinary metals at room temperature. In thermistor "material 1," which commonly is used, the coefficient at 25 degrees centigrade is −4.4 per cent per degree centigrade, or over ten times that of copper, which is +0.39 per cent per degree centigrade at the same temperature. A circuit element made of this thermistor material has a resistance at zero degrees centigrade which is nine tines the resistance of the same element at 50 degrees centigrade. For comparison, the resistance of a copper wire at 50 degrees centigrade is 1.21 times its value at zero degrees centigrade.

The resistance-temperature characteristics of thermistors suggest their use as sensitive thermometers, as temperature

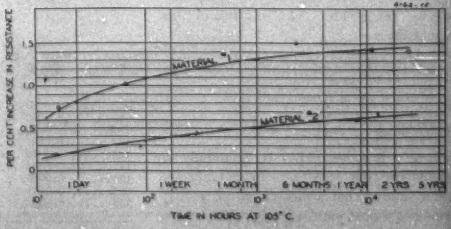


Figure 15. Aging characteristic of thermistors made of materials 1 and 2 aged in an oven at 105 degrees centigrade

Per cent increase in resistance over its initial value versus time on a logarithmic scale

actuated controls, and as compensators for the effects of varying ambient temperature on other elements in electric circuits.

Thermometry

The application of thermistors to temperature measurement follows the usual principles of resistance thermometry. However, the large value of temperature coefficient of thermistors permits a new order of sensitivity to be obtained. This and the small size, simplicity, and ruggedness of thermistors adapt them to a wide variety of temperature measuring applications. When designed for this service, thermistor thermometers have long-time stability which is good for temperatures up to 300 degrees centigrade and excellent for more moderate temperatures. A well-aged thermistor used in precision temperature measurements was found to be within 0.01 degree centigrade of its calibration after two months use at various temperatures up to 100 degrees centigrade. As development proceeds, the stability of thermistor thermometers may be expected to approach that of precision platinum thermometers. Conventional bridge or other resistance measuring circuits commonly are employed with thermistors. As with any resistance thermometer, consideration must be given to keeping the measuring current sufficiently small so that it produces no appreciable heating in order that the thermistor resistance shall be dependent upon the ambient temperature alone.

Since thermistors are readily designed for higher resistance values than metallic resistance thermometers or thermocouples, lead resistances ordinarily are not bothersome. Hence the temperature sensitive element can be located remotely from its associated measuring circuit. This permits great flexibility in application, such, for instance, as wire line transmission of temperature indications to control points.

Table II. Temperature–Resistance Characteristic of a Typical Thermistor Thermometer

Temp, Deg C	Resistance, Ohms	Temp Coefficients B, Deg C	Temp Coefficients α, Per Cent Per Deg C
−25	580,000	3,780	−6.1
0	145,000	3,850	−5.2
25	46,000	3,920	−4.4
50	16,400	3,980	−3.8
75	6,700	4,050	−3.3
100	3,200	4,120	−3.0
150	830	4,260	−2.4
200	305	4,410	−2.0
275	100	4,600	−1.5

Dissipation constant in still air, approximately 4 milliwatts per degree centigrade; thermal time constant in still air, approximately 70 seconds; dimensions of thermistor, diameter approximately 0.11 inch, length approximately 0.54 inch.

Figure 16. Logarithmic plots of voltage versus current for six values of heater current in an indirectly heated thermistor

Resistance and power scales are given on the diagonal lines

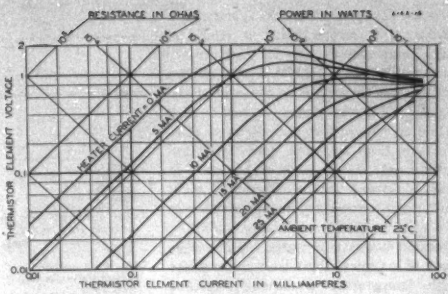


Table II gives the characteristics of a typical thermistor thermometer. The dissipation constant is the ratio of the power input in watts dissipated in the thermistor, to the resultant temperature rise in degrees centigrade. The time constant is the time required for the temperature of the thermistor to change 63 per cent of the difference between its initial value and that of the surroundings. As a sensitive thermometer, this thermistor with a simple Wheatstone bridge and a galvanometer whose sensitivity is 2×10^{-10} amperes per millimeter per meter will indicate readily a temperature change of 0.0005 degree centigrade. For comparison, a precision platinum resistance thermometer and the required special bridge such as the Mueller, will indicate a minimum change of 0.003 degree centigrade with a similar galvanometer.

Several thermistors which have been used for thermometry are shown in Figure 17. Included in the group are types which are suited to such diverse applications as intravenous blood thermometry and supercharger rotor temperature measurement. In Figure 17, *A* is a tiny bead with a response time of less than a second in air. *B* is a probe type unit for use in air streams or liquids. *C* is a meteorological thermometer used in automatic radio transmission of weather data from free balloons. *D* is a rod shaped unit. *E* is a disk or pellet, adapted for use in a metal thermometer bulb. Disks like the one shown have been sweated to metal plates to give a low thermal impedance connection to the object whose temperature is to be determined. *F* is a large disk with an enveloping paint finish for use in humid surroundings. The characteristics of these types are given in Table III.

The temperature of objects which are inaccessible, in motion, or too hot for contact thermometry, can be determined by permitting radiation from the object to be focused on a suitable thermistor by means of an elliptical mirror. Such a thermistor may take the form of a thin flake attached to a solid support. Its advantages compared with the thermopile and resistance bolometer are its more favorable resistance value, its ruggedness, and its high temperature coefficient of resistance. It can be made small to reduce its heat capacity so as to follow rapidly changing temperatures. Flake thermistors have been made with time constants from one millisecond to one second. Since the amount of radiant power falling on the thermistor may be quite small, sensitive meters or vacuum tube amplifiers are required to measure the small changes in the flake resistance. Where rapidly varying temperatures are not involved, thermistors with longer time constants and simpler circuit equipments can be utilized.

Temperature Control

The use of thermistors for temperature control purposes is related closely to their application as temperature measuring devices. In the ideal temperature-sensitive control element, sensitivity to temperature change should be high and the resistance value at the control temperature should be the proper value for the control circuit used. Also, the temperature rise of the control element resulting from circuit heating should be low, and the stability of calibration should be good. The size and shape of the sensitive element are dictated by several factors such as the space available, the required speed of response to temperature changes, and the amount of power which must be dissipated in the element by the control circuit to permit the arrangement to operate relays, motors, or valves.

Because of their high temperature sensitivity, thermistors have shown much

promise as control elements. Their adaptability and their stability at relatively high temperatures led, for instance, to an aircraft engine control system using a rod-shaped thermistor as the control element.[9] The thermistor, mounted in a standard one-quarter inch diameter temperature bulb assembly, operated at approximately 275 degrees centigrade. It was associated with a differential relay and control motor on the aircraft 28-volt d-c system. The power dissipation in the thermistor was two watts. The resistance of a typical thermistor under these high temperature conditions remained within ±1.5 per cent over a period of months. This corresponds to about ± one degree centigrade variation in calibration. Several other related designs were developed using the same control system with other thermistors designed for both higher and lower temperature operation. In the lower temperature applications, typical thermistors maintained their calibrations within a few tenths of a degree centigrade.

In general, gas tube control circuits dissipate less power in the thermistor than relay circuits do. This results in less temperature rise in the thermistor, and leads to a more accurate control. While the average value of this temperature rise can be allowed for in the design, the variations in different installations require individual calibration to correct the errors if they are large. The corrections may be different as a result of variations of the thermal conductivity of the surrounding media from time to time, or from one installation to another. The greater the power dissipated in the thermistor, the greater the absolute error in the control temperature for a given change in thermal conductivity. This follows from the relation

$$\Delta T = W/C \qquad (22)$$

where ΔT is the temperature rise, W is the power dissipated, and C is the dissipation constant which depends on thermal coupling to the surroundings. For the same reason, the temperature indicated by a resistance thermometer immersed in an agitated medium will depend on the rate of flow if the temperature sensitive element is operated several degrees hotter than its surroundings.

The design of a thermistor for a ventilating duct thermostat might proceed as follows as far as temperature rise is concerned:

1. Determine the power dissipation. This depends upon the circuit selected and the required over-all sensitivity.

2. Estimate the permissible temperature rise of the thermistor, set by the expected variation in air speed and the required temperature control accuracy.

3. Solve equation 22 for the dissipation constant and select a thermistor of appropriate design and size for this constant in the nominal air speed. Where more than one style of thermistor is available, the required time constant will determine the choice.

Table III. Thermistor Thermometers

	A	B	C	D	E	F
Nominal resistance, ohms:						
−25 C	—	—	87,500	610,000	—	13,000
0 C	5,000	325,000	37,500	153,000	490	3,200
25 C	2,000	100,000	18,000	48,500	175	950
50 C	900	33,000	9,700	17,300	71	340
75 C	460	13,000	5,500	7,100	32	145
100 C	250	6,000	3,700	3,400	16	70
150 C	95	1,600	—	870	4.5	—
200 C	—	500	—	—	1.6	—
300 C	—	80	—	—	—	—
Temp coefficient α, per cent per deg C at 25 C	−3.4	−4.4	−2.8	−4.4	−3.8	−4.4
Max permissible temp, deg C	150	300	100	150	200	100
Dissipation constant, C, milliwatts per deg C:						
Still air	0.1	1	7	7	—	20
Still water	—	7	—	—	—	—
Thermal time constant, sec:						
Still air	1	30	25	60	—	—
Still water	—	4	—	—	—	—
Shape	Bead	Probe	Rod	Rod	Disk	Disk
Dimensions, inches:						
Diameter or width	0.015	0.1	0.05	0.15	0.2	0.55
Length or thickness (less leads)	0.02	0.6	1.2	0.7	0.1	0.31

Compensators

It is a natural and obvious application of thermistors to use them to compensate for changes in resistance of electrical circuits caused by ambient temperature variations. A simple example is the compensation of a copper wire line, the resistance of which increases approximately 0.4 per cent per degree centigrade. A thermistor having approximately one-tenth the resistance of the copper, with a temperature coefficient of −4 per cent per degree centigrade placed in series with the line and subjected to the same ambient temperature, would serve to compensate it over a narrow temperature range. In practice however, the compensating thermistor is associated with parallel and sometimes series resistance, so that the combination gives a change in resistance closely equal and opposite to that of the circuit to be compensated over a wide range of temperatures. See Figure 18.

A copper winding having a resistance of 1,000 ohms at 25 degrees centigrade can be compensated by means of a thermistor of 566 ohms at 25 degrees centigrade in parallel with an ohmic resistance of 445 ohms as shown in Figure 18. The winding with compensator has a resistance of 1,250 ohms constant to ±1.6 per cent over the temperature range −25 degrees centigrade to +75 degrees centigrade. Over this range the copper alone varies from 807.5 ohms to 1,192.5 ohms, or ±19 per cent. The total resistance of the circuit has been increased only 6.1 per cent at the upper temperature limit by the addition of a compensator. This increase is small because of the high temperature coefficient of the compensating thermistor. The characteristics of such a thermistor are so stable that the resistance would remain constant within less than one per cent for ten years, if maintained at any temperature up to about 100 degrees centigrade. Figure 15 shows aging characteristics for typical thermistors suitable for use in compensators. These curves include the change which occurs during the seasoning period of several days at the factory, so that the aging in use is a fraction of the total shown.

In many circuits which need to function to close tolerances under wide ambient temperature variation, the values of one or more circuit elements may vary undesirably with temperature. Frequently the resultant over-all variation with temperature can be reduced by the insertion of a simple thermistor placed at an appropriate point in the circuit. This is true particularly if the circuit contains vacuum tube amplifiers. In this manner, frequency and gain shifts in communications circuits have been cancelled and temperature errors prevented in the operation of devices such, for instance, as electric meters. The change in inductance of a coil resulting from the variation of magnetic characteristics of the core ma-

terial with temperature has been prevented by partially saturating the coil with direct current, the magnitude of which is directly controlled by the resistance of a thermistor imbedded in the core. In this way the amount of d-c magnetic flux is adjusted by the thermistor so that the inductance of the coil is independent of temperature.

In designing a compensator, care must be taken to ensure exposure of the thermistor to the temperature affecting the element to be compensated. Power dissipation in the thermistor must be considered and either limited to a value which will not produce a significant rise in temperature above ambient temperature, or offset in the design.

Volt-Ampere Characteristics

The nonlinear shape of the static characteristic relating voltage, current, resistance, and power for a typical thermistor was illustrated by Figure 9. The part of the curve to the right of the voltage maximum has a negative slope, applicable in a large number of ways in electric circuits. The particular characteristic shown begins with a resistance of approximately 50,000 ohms at low power. Additional power dissipation raises the temperature of the thermistor element and decreases its resistance. At the voltage maximum, the resistance is reduced to about one-third its cold value, or 17,000 ohms, and the dissipation is 13 milliwatts. The resistance becomes approximately 300 ohms when the dissipation is 100 milliwatts. Such resistance-power characteristics have resulted in the use of thermistors as sensitive power measuring devices, and as automatically variable resistances for such applications as output amplitude controls for oscillators and amplifiers. Their nonlinear characteristics also fit thermistors for use as voltage regulators, volume controls, expandors, contactless switches, and remote control devices. To permit their use in these applications for d-c as well as a-c circuits, nonpolarizing semiconductors alone are employed in thermistors with the exception of two early types.

Power Meter

Thermistors have been used very extensively in the ultra- and superhigh frequency ranges in test sets as power measuring elements. The particular advantages of thermistors for this use are that they can be made small in size, have a small electrical capacity, can be severely overloaded without change in calibration, and easily can be calibrated with d-c or low frequency power. For this application the thermistor is used as a power absorbing terminating resistance in the transmission line, which may be of Lecher, coaxial, or wave-guide form. Methods of mounting have been worked out which reduce the reflection of high frequency energy from the termination to negligible values, and assure accurate measurement of the power over broad bands in the frequency spectrum. Conventionally, the thermistor is operated as one arm of a Wheatstone bridge, and is biased with low frequency or d-c energy to a selected operating resistance value, for instance, 125 or 250 ohms in the absence of the power to be measured. The application of the power to be measured further decreases the thermistor resistance, the bridge becomes unbalanced, and a deflection is obtained on the bridge meter. A full scale power indication of one milliwatt is customary for the test set described, although values from 0.1 milliwatt to 200 milliwatts have been employed using thermistors with different sized beads as shown in Figure 19.

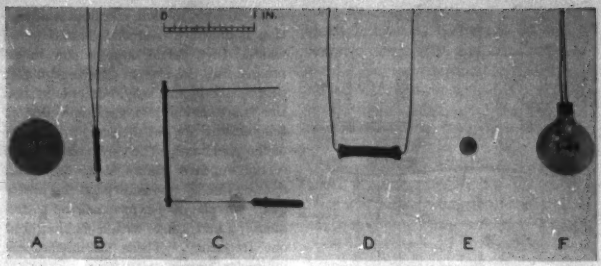


Figure 17. Some forms of thermistors which have been used as resistance thermometers

Continuous operation tests of these thermistors indicate very satisfactory stability with an indefinitely long life. A group of eight power meter thermistors, normally operated at 10 milliwatts and having a maximum rating of 20 milliwatts, were operated for over 3,000 hours at a power input of 30 milliwatts. During this time the room temperature resistance remained within 1.5 per cent of its initial value, and the power sensitivity, which is the significant characteristic, changed by less than 0.5 per cent.

When power measuring test sets are intended for use with wide ambient temperature variations, it is necessary to temperature compensate the thermistor. This is accomplished conventionally by the introduction of two other thermistors into the bridge circuit. These units are designed to be insensitive to bridge currents but responsive to ambient temperature. One of the compensators maintains the zero point and the other holds the meter scale calibration independent of the effect of temperature change on the measuring thermistor characteristics.

Automatic Oscillator Amplitude Control

Meacham,[10] and Shepherd and Wise[11] have described the use of thermistors to provide an effective method of amplitude stabilization of both low and high frequency oscillators. These circuits oscillate because of positive feedback around the vacuum tube. The feed-back circuit is a bridge with at least one arm containing a thermistor which is heated by the oscillator output. Through this arrangement, the feedback depends in phase and magnitude upon the output, and there is one value of thermistor resistance which, if attained, would balance the bridge and cause the oscillation amplitude to vanish. Obviously this condition never can be exactly attained, and the operating point is just enough different to keep the bridge slightly unbalanced and produce a predetermined steady value of oscillation output. Such oscillators in which the amplitude is determined by thermistor nonlinearity have manifold advantages over those whose amplitude is limited by vacuum tube nonlinearity. The harmonic content in the output is smaller, and the performance is much less dependent upon the individual vacuum tube and upon variations of the supply voltages. It is necessary that the thermal inertia of the thermistor be sufficient to prevent it from varying in resistance at the oscillation frequency. This is satisfied easily for all frequencies down to a small fraction of a cycle per second. Figure 20 shows a thermistor frequently used for oscillator control, together with its static

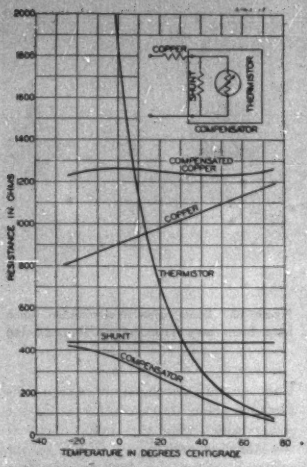


Figure 18. Temperature compensation of a copper conductor by means of a thermistor network

electrical characteristic. This thermistor is satisfactory in oscillators for frequencies above approximately 100 cycles per second. Similar types have been developed with response characteristics suited to lower frequencies, and for other resistance values and powers.

Where the ambient temperature sensitivity of the thermistor is disadvantageous in oscillator controls, the thermistor can be compensated by thermostating it with a heater and compensating thermistor network, as shown in Figure 21.

Amplifier Automatic Gain Control

Since the resistance of a thermistor of suitable design varies markedly with the power dissipated in it or in a closely associated heater, such thermistors have proved to be very valuable as automatic gain controls, especially for use with negative feed-back amplifiers. This arrangement has seen extensive use in wire communication circuits for transmission level regulation, and has been described in some detail elsewhere.[12–14] In one form, a directly heated thermistor is connected into the feed-back circuit of the amplifier in such a way that the amount of feed-back voltage is varied to compensate for any change in the output signal. By this arrangement, the gain of each amplifier in the transmission system is adjusted continually to correct for variations in overall loss due to weather conditions and other factors, so that constant transmission is obtained over the channel at all times. In a carrier system now in extensive use, the system gain is regulated principally in this way. In this system the transmission loss variations due to temperature are not the same in all parts of the pass band. The loss is corrected at certain repeater points along the transmission line by two additional thermistor gain controls: slope, proportional to frequency; and bulge, with a maximum at one frequency. These thermistors are indirectly heated, with their heaters actuated by energy dependent upon the amplitude of the separate pilot carriers, which are introduced at the sending end for the purpose.

In this type of application, the thermistor will react to the ambient temperature to which it is exposed, as well as to the current passing through it. Where this is important, the reaction to ambient temperature can be eliminated by the use of a heater-type thermistor as shown in Figure 21. The heater is connected to an auxiliary circuit containing a temperature compensating thermistor. This circuit is so arranged that the power fed into the heater of the gain control thermistor is just sufficient at any ambient temperature to give a controlled and constant value of temperature in the vicinity of the gain control thermistor element.

Another interesting form of thermistor gain control utilizes a heater-type thermistor, with the heater driven by the output of the amplifier and with the thermistor element in the input circuit, as shown in Figure 22. In this arrangement, the feedback is accomplished by thermal, rather than electrical coupling. A broadband carrier system, now in use, is regulated with this type of thermistor. In this system a pilot frequency is supplied, and current of this frequency, selected by a network in the regulator, actuates the heater of the thermistor to give smooth, continuous gain control.

By utilizing a heater thermistor of different characteristics, the circuit and load of Figure 22 may be given protection against overloads. In this application, the sensitivity and element resistance of the thermistor are chosen so that the thermistor element forms a shunt of high resistance value, so as to have negligible effect on the amplifier for any normal value of output. However, if the output power rises to an abnormal level, the thermistor element becomes heated and reduced in resistance. This shunts the input to the amplifier, and thus limits the output. Choice of a thermistor having a suitable time constant permits the onset of the limiting effect to be delayed

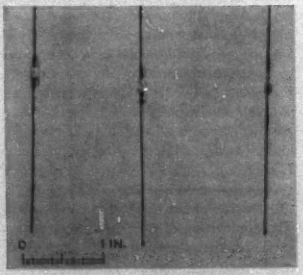


Figure 19. Power measuring thermistors with different sized beads

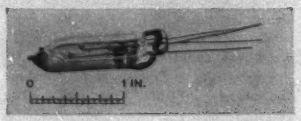


Figure 20A (above). An amplitude control thermistor

The glass bulb is 1.5 inches in length

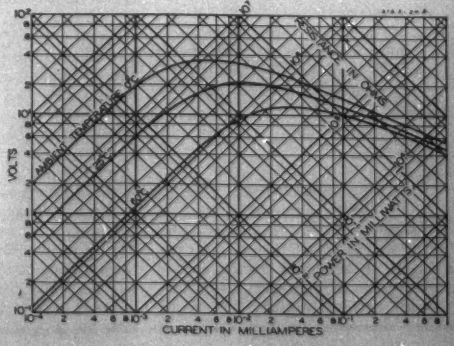


Figure 20B (right). Steady state characteristics of amplitude control thermistor shown in Figure 20A

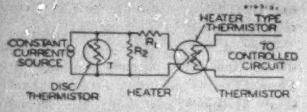


Figure 21. Circuit employing an auxiliary disk thermistor to compensate for effect of varying ambient temperature on a control thermistor

for any period from about a second to a few minutes.

Regulators and Limiters

A group of related applications for thermistors depends on their steady state nonlinear volt-ampere characteristic. These are the voltage regulator, the speech volume limiter, the compressor, and the expandor. The compressor and expandor are devices for altering the range of signal amplitudes. The compressor functions to reduce the range, while the expandor increases it. In Figure 23, curve 1 is a typical thermistor static characteristic having negative slope to the right of the voltage maximum. Curve 2 is the characteristic of an ohmic resistance R having an equal but positive slope. Curve 3 is the characteristic obtained if the thermistor and resistor are placed in series. It has an extensive segment where the voltage is almost independent of the current. This is the condition for a voltage regulator or limiter. If a larger value of resistance is used, as in curve 4, its combination with the thermistor in series results in curve 5, the compressor. In these uses the thermistor regulator is in shunt with the load resistance, so that

$$E = E_o = E_I - IR_s \qquad (23)$$

in the circuit diagram of Figure 23. Here E is the voltage across the thermistor and resistor R, E_o is the output voltage, and E_I, I and R_s are respectively, the input voltage, current, and resistance.

If the thermistor and associated resistor are placed in series between the generator and load resistance, an expandor is obtained, and

$$E_o = E_I - E \qquad (24)$$

As the resistance R in series with the thermistor is increased, the degree of expansion is decreased, and vice versa.

The treatment thus far in this section assumes that change of operating point occurs slowly enough to follow along the static curves. For a sufficiently rapid change of the operating point, the latter departs from the static curve and tends to progress along an ohmic resistance line intersecting the static curve. For sufficiently rapid fluctuations, control action then may be derived from the resistance changes resulting from the rms power dissipated in the thermistor unit. In speech volume limiters, the thermistor is designed for a speed of response that will produce limiting action for the changes in volume which are syllabic in frequency or slower, and that will not follow the more rapid speech fluctuations with resulting change in wave shape or nonlinear distortion. Speech volume limiters of this type can accommodate large volume changes without producing wave form distortion.[13,15]

Remote Control Switches

The contactless switch and rheostat are natural extensions of the uses just discussed. The thermistor is used as an element in the circuit which is to be controlled, while the thermistor resistance value is, in turn, dependent upon the energy dissipated directly or indirectly in it by the controlling circuit. By taking advantage of the nonlinearity of the static volt-ampere characteristic, it is possible to provide snap and lock-in action in some applications.

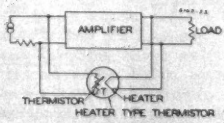


Figure 22. Thermal feed-back circuit for gain control purposes

This arrangement has also been used as a protective circuit for overloads

Manometer

Several interesting and useful applications such as vacuum gauges, gas analyzers, flowmeters, thermal conductivity meters, and liquid level gauges of high sensitivity and low operating temperature are based upon the physical principle that the dissipation constant of the thermistor depends on the thermal conductivity of the medium in which it is immersed. As shown in Figure 10, a change in this constant shifts the position of the static characteristic with respect to the axes. In these applications, the undesired response of the thermistor to the ambient temperature of the medium can, in many cases, be eliminated or reduced by introducing a second thermistor of similar characteristics into the measuring circuit. The compensating thermistor is subjected to the same ambient temperature, but is shielded from the effect being measured, such as gas pressure or flow. The two thermistors can be connected into adjacent arms of a Wheatstone bridge which is balanced when the test effect is zero, and becomes unbalanced when the effective thermal conductivity of the medium is increased. In gas flow measurements, the minimum measurable velocity is limited, as in all hot wire devices, by the convection currents produced by the heated thermistor.

The vacuum gauge or manometer which is typical of these applications will be described somewhat in detail. The sensitive element of the thermistor manometer is a small glass coated bead 0.02 inch in diameter, suspended by two fine wire leads in a tubular bulb for attachment to the chamber whose gas pressure is to be measured. The volt-ampere characteristics of a typical laboratory model manometer are shown in Figure 24 for air at several absolute pressures from 10^{-4} millimeters of mercury to atmospheric pressure. The operating point, in general, is to the right of the peak of these curves. Electrically this element is connected into a unity ratio arm Wheatstone bridge with a similar, but evacuated, thermistor in an adjacent arm as shown in the circuit schematic of Figure

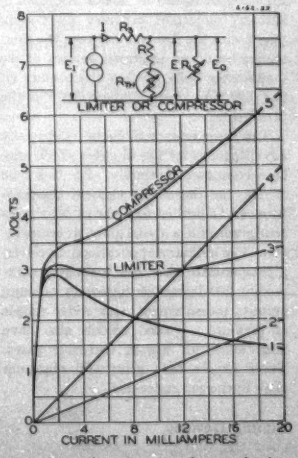


Figure 23. Characteristics of a simple thermistor voltage regulator, limiter, or compressor circuit

25. The air pressure calibration for such a manometer is also shown. The characteristic will be shifted when a gas is used having a thermal conductivity different from that of air. Such a manometer has been found to be best suited for the measurement of pressures from 10^{-4} to 10 millimeters of mercury. The lower pressure limit is set by practical considerations, such as meter sensitivity and the ability to maintain the zero setting

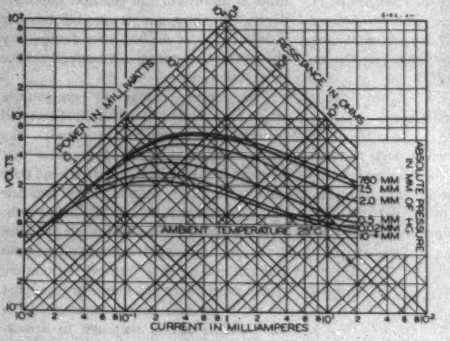


Figure 24 (left). Characteristics of a typical thermistor manometer tube, showing the effect of gas pressure on the volt-ampere and resistance-power relations

for reasonable periods of time in the presence of the variations of supply voltage and ambient temperature. The upper pressure measurement limit is caused by the onset of saturation in the bridge unbalance voltage versus pressure characteristic at high pressures. This is basically because the mean free path of the gas molecules becomes short compared with the distance between the thermistor bead and the inner surface of the manometer bulb, so that the cooling effect becomes nearly independent of the pressure.

The thermistor manometer is specially advantageous for use in gases which may be decomposed thermally. For this type of use, the thermistor element temperature can be limited to a rise of 30 degrees centigrade or less above ambient temperature. For ordinary applications, however, a temperature rise over a range not exceeding 200 degrees centigrade in vacuum, permits measurement over wider ranges of pressure. Special models also have been made for use in corrosive gases. These expose only glass and platinum alloy to the gas under test.

Timing Devices

The numerically greatest application for thermistors in the communication field has been for time delay purposes. The physical basis for this use has been discussed in part I for the case of a directly heated thermistor placed in series with a voltage source and a load, to delay the current rise after circuit closure. This type of operation will be termed the power driven time delay.

By the use of a thermistor suited to the circuit and operating conditions, power driven time delays can be produced from a few milliseconds to the order of a few

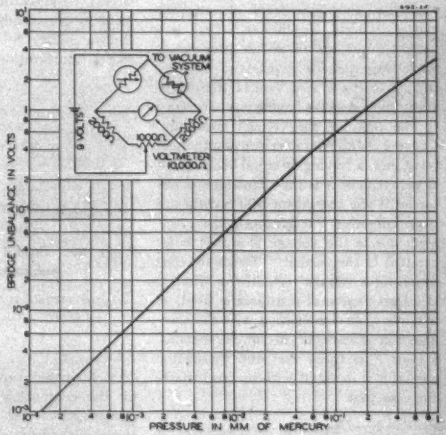


Figure 25 (right). Operating circuit and calibration for a vacuum gauge utilizing the thermistor of Figure 24

minutes. Thermistors of this sort have the advantage of small size, light weight, ruggedness, indefinitely long life, and absence of contacts, moving parts, or pneumatic orifices which require maintenance care. Power driven time delay thermistors are best fitted for applications where close limits on the time interval are not required. In some communications uses, it is satisfactory to permit a six to one ratio between maximum and minimum times as a result of the simultaneous variation from nominal values of all the following factors which affect the delay: operating voltage ± five per cent; ambient temperature 20 degrees centigrade to 40 degrees centigrade; operating current of the relay ±25 per cent; relay resistance ± five per cent; and thermistor variations such as occur from unit to unit of the same type.

After a timing operation, a power driven time delay thermistor should be allowed time to cool before a second operation. If this is not done, the second timing interval will be shorter than the first. The cooling period depends on particular circuit conditions and details of thermistor design, but generally is several times the working time delay. In telephone relay circuits requiring a timing operation soon after previous use, the thermistor usually is connected so that it is short circuited by the relay contacts at the close of the working time delay interval. This permits the thermistor to cool during the period when the relay is locked up. If this period is sufficiently long, the thermistor is available for use as soon as the relay drops out. Time delay thermistors have been operated more than half a million times on life test, with no significant change in their timing action.

To avoid the limitations of wide timing interval limits and extended cooling periods between operations usually associated with the power driven time delay thermistor, a cooling time delay method of operation has been used. In this arrangement, two relays or the equivalent are employed, and the thermistor is heated to a low resistance value by passing a relatively large current through it for an interval, short compared with the desired time interval. The current then is reduced automatically to a lower value, and the thermistor cools until its resistance increases enough to reduce the current further and trip the working relay.

This part of the operating cycle accounts for the greater part of the desired time interval. With this arrangement, the thermistor is available for reuse immediately after a completed timing interval, or, as a matter of fact, after any part of it. By proper choice of operating currents and circuit values, wide variations of voltage and ambient temperature may occur with relatively little effect upon the time interval. The principal variable left is the cooling time of the thermistor itself. This is fixed in a given thermistor unit, but may vary from unit to unit, depending upon dissipation constant and thermal capacity, as pointed out above.

In addition to their use as definite time delay devices, thermistors have been used in several related applications. Surges can be prevented from operating relays or disturbing sensitive apparatus by introducing a thermistor in series with the circuit component which is to be protected. In case of a surge, the high initial resistance of the thermistor holds the surge current to a low value, provided that the surge does not persist long enough to overcome the thermal inertia of the thermistor. The normal operating voltage, on the other hand, is applied long enough to lower the thermistor resistance to a negligible value, so that a normal operating current will flow after a short interval. In this way, the thermistor enables the circuit to distinguish between an undesired signal of short duration and a desired signal of longer duration, even though the undesired impulse is several times higher in voltage than the signal.

Oscillators, Modulators, and Amplifiers

A group of applications, already explored in the laboratory but not put into engineering use, includes oscillators, modulators, and amplifiers for the low and audio-frequency range. If a thermistor is biased at a point on the negative slope portion of the steady-state volt-ampere characteristic, and if a small alternating voltage is then superposed on the direct voltage, a small alternating current will flow. If the thermistor has a small time constant, τ, and if the applied frequency is low enough, the alternating volt-ampere characteristic will follow the steady-state curve and dV/dI will be negative. As the frequency of the applied alternating voltage is increased, the value of the negative resistance decreases. At some critical frequency, f_c, the resistance is zero and the current is 90 degrees out of phase with the voltage. In the neighborhood of f_c, the thermistor acts like an inductance whose value is of the order of a henry. As the frequency is increased beyond f_c, the resistance is positive, and increases steadily until it approaches the d-c value when the current and voltage are in phase. The critical frequency is approximately given by

$$f_c = 1/\tau \qquad (25)$$

If τ can be made as small as 5×10^{-4} seconds, f_c is equal to 10,000 cycles per second, and the thermistor would have an approximately constant negative resistance up to half this frequency. Point contact thermistors, having such critical frequencies or even higher, have been made in a number of laboratories. However, none of them has been made with sufficient reproducibility and constancy to be useful to the engineer. It has been shown both theoretically and experimentally that any negative resistance device can be used as an oscillator, a modulator, or an amplifier. With further development, it seems probable that thermistors will be used in these fields.

Summary

The general principles of thermistor operation, and examples of specific uses have been given to facilitate a better understanding of thermistors, with the feeling that such an understanding will be the basis for increased use of this new circuit and control element in technology.

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Characteristics of Resistance Welding Transformers

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RESISTANCE WELDING as a labor saving production method has made tremendous strides in the past decade. Its widespread recognition during World War II has made it quite evident that this art will be used even more universally in the postwar era.

When one considers that the heart of the resistance welding machine is its transformer, it appears quite logical that an explanation of this type transformer is forthcoming.

It is the purpose of this paper to present the characteristics and functions of the resistance welding transformer in addition to the design problems encountered.

The subject is much too large to enable a detailed discussion and derivation of all the mathematics required to determine the design constants used in this field. Emphasis has been placed on the general problems of design and the effects of deviations from standard practice.

Functions of a Resistance Welding Transformer

The resistance welding transformer, in common with all transformers, is a device for transferring energy by means of electromagnetic induction.

The function of a resistance welding transformer is to furnish relatively large currents at comparably low voltages from the mains of its user's power supply. When delivering load the transformer can be considered, for all practical purposes, as under short-circuit conditions. Its current is limited only by the impedance of the welder plus a small impedance caused by the work.

Standards Governing Resistance Welding Transformers

The Resistance Welder Manufacturers Association has set up standards covering transformers used in resistance welding machines.

The capacity of resistance welding transformers is rated in kilovolt-amperes at 50 per cent duty cycle. The continuous duty rating of such transformers then becomes 0.707 times the name plate rating.

The duty cycle expressed in per cent is considered to be the ratio of weld time in cycles per minute to the total cycles in a minute times 100.

$$\text{Per cent duty cycle on 60 cycles} = \frac{\text{cycles of weld time in a minute}}{3{,}600} \times 100 \quad (1)$$

As the users of resistance welding equipment usually are more concerned with the permissible duty cycle for a given load than they are with the name plate rating, it often is desired to convert as follows:

$$\text{Permissible duty cycle in per cent} = \left(\frac{\text{rated kilovolt-amperes} \times 7.07}{\text{load kilovolt-amperes}}\right)^2 \quad (2)$$

These same standards require that the exciting currents be limited in proportion to the rated current. Transformers rated at less than 100 kva are permitted an exciting current of ten per cent of the rated current, while those rated 100 kva or over are limited to exciting currents of only five per cent of the rated current.

Insulations are required to be able to withstand twice the maximum induced voltage plus 1,000 volts for a period of one minute.

The permitted temperature rise is governed by the type of insulation used. Transformers in which class *B* insulation is used are limited to a temperature rise of 80 degrees centigrade, while those in which class *A* insulation is used are permitted only 60 degrees centigrade rise, as measured by the thermocouple method.

Design Restrictions

The design of resistance welding transformers can be approached only after consideration of several points of limitation.

1. The geometry of the transformer frequently is determined by the available space provided in the welding unit.
2. The limitations as set forth by the RWMA must be met.
3. It is desired to minimize the losses.
4. Economics dictate the manufacture of equipment at a reasonable cost.
5. The number of secondary turns usually is limited to one.

Core Design

The use of high-grade low-watt-loss silicon steel permits the use of higher flux densities for the same hysteresis losses.

Flux densities of from 75,000 to 85,000 lines per square inch (depending on the kilovolt-ampere rating) may be used when it is desired to limit the exciting currents to those values as set forth by the RWMA

From the general formula,

$$E = 4.44NfKBA \times 10^{-8} \quad (3)$$

and assuming a stacking factor of 0.95,

$$B = 395{,}000\frac{E}{NA} \quad (4)$$

when $f = 60$ cycles per second.

$$\frac{A}{\frac{E}{N}} = \frac{395{,}000}{B} \quad (5)$$

This formula gives the area of required core in square inches per volt per turn for a given flux density. Note Figure 1 for flux density versus area.

The core dimensions can be proportioned to suit the available space within certain limitations. A core which takes the form of a square results in a mean turn of minimum length and is the most economical design.

Where space dictates the use of other proportions, the length should not exceed the height by a factor of more than three to one.

Design of the High Voltage Winding

The high voltage winding usually is arranged with eight taps for heat adjustment. Where electronic controls with incorporated heat adjustment facilities are provided, a series-parallel winding without taps is becoming more popular.

The principal advantage of the series-parallel winding is increased duty cycle when less than the maximum load is required. This is true because the copper cross section remains constant as the heat is phased back.

When resistance welding transformers are provided with taps for heat adjustment the copper cross section of the high voltage winding may be reduced as the

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square of the open circuit volts across the low voltage winding. In practical design this method of calculating copper densities should be used as a minimum with space dictating how closely it is approached.

Tapering the copper cross section in this manner keeps the permissible duty cycle constant for any tap. Mathematical analysis of this will be shown.

Duty cycle is a function of kilovolt-ampere demand and rating. Then, given a welder of known kilovolt-amperes and duty cycle, it is desired to maintain the duty cycle as the load decreases.

$$\text{Demand kilovolt-amperes} = \frac{E_2 I_2}{1000} \quad (6)$$

The low voltage winding current varies directly as its open circuit volts; hence,

$$\frac{E_{21}}{E_{22}} = \frac{I_{21}}{I_{22}} \quad (7)$$

$$I_{22} = \frac{I_{21} E_{22}}{E_{21}} \quad (8)$$

$$KVA_1 = \frac{E_{21} I_{21}}{1000} \quad (9)$$

$$KVA_2 = \frac{E_{22} I_{22}}{1000} \quad (10)$$

Divide one by the other:

$$\frac{KVA_1}{KVA_2} = \frac{E_{21} I_{21}}{E_{22} I_{22}} \quad (11)$$

Substitute and simplify:

$$\frac{KVA_1}{KVA_2} = \frac{E_{21} I_{21} E_{21}}{E_{22} I_{21} E_{22}} = \frac{E_{21}^2}{E_{22}^2} \quad (12)$$

From experience gathered from data on many welding transformers, the following copper densities may be used without exceeding permissible temperature rises for the two types shown:

1. For a pancake type of winding pressed tight against a water-cooled secondary winding insulated from primary winding with mica barriers, a density of 2,500 amperes per square inch may be used at 50 per cent duty cycle rating of transformer.

2. For a layer type of winding, air-cooled and used with a secondary winding not water-cooled, the permissible copper density is 1,500 amperes per square inch. This type of transformer usually has the low voltage winding or secondary made of a laminated copper band built up to the required thickness. The impedance is higher than the pancake type of winding.

Density of Low Voltage or Secondary Winding

The low voltage winding generally is made of cast copper having a minimum of 85 per cent conductivity. Water-cooling pipes are cast into or welded to the outside of the casting. When pipes are cast integral with the secondary, the casting usually is increased in thickness to allow for pipe. When copper tubing is welded to the outside of the secondary section, the thickness can be reduced to the diameter of the tubing. The impedance, therefore, is lowered by using thin sections approximately one-half inch thick and more of them than by the use of a thick section. Under ordinary conditions of cooling water temperature, the density of current in the secondary casting can be 3,200 amperes per square inch at a 50 per cent duty cycle rating.

The secondary winding current will tend to crowd at the corners and the mean turn with respect to current flow will be slightly less than when figured in the conventional manner. The calculated resistance, therefore, will give higher copper loss than actual measurement during impedance test.

Design of 100-Kva Transformer

This transformer is a 440-volt 60-cycle type with 50 per cent duty cycle. The required open circuit volts (E_2) is 6.67 with 1-turn low voltage winding.

Core Size

B = 77,000 lines per square inch (assumed)

$$A = \frac{E}{N} \times \frac{395{,}000}{B} = \frac{6.67}{1} \times \frac{395{,}000}{77{,}000} = 34.2 \text{ square inches} \quad (13)$$

High Voltage or Primary Winding

$$I_p \text{ (rated)} = \frac{100{,}000}{440} = 227 \text{ amperes} \quad (14)$$

$$\text{Copper section} = 227 \times \frac{1}{2{,}500} = 0.0908 \text{ square inch} = 90{,}800 \text{ square mils} \quad (15)$$

$$\text{Number of turns for maximum } E_2 = \frac{440}{6.67} = 66 \quad (16)$$

The high voltage winding will be proportioned for a series-parallel arrangement as shown in Figure 11.

The insulation between turns for a class B design can be any one of several materials. In this case the authors would choose 0.020-inch mica.

The width of primary winding copper should be kept as small as practical with one-fourth inch as the minimum. An increase in width will increase the copper loss. A practical width for this design would be 0.625 inch. As the primary winding is split into two sections, the required copper per section is

$$\frac{90{,}800}{2} = 45{,}400 \text{ square mils} = 0.0454 \text{ square inch} \quad (17)$$

The thickness of the copper per turn is $\frac{0.0454}{0.625} = 0.0728$ inch. Use 0.075 inch × 0.625 inch for practical reasons.

Therefore, the total height of high voltage winding = (0.075 + 0.020) × 33 = 3.13 inches.

Low Voltage or Secondary Winding

$$I_2 \text{ (rated)} = \frac{100{,}000}{6.67} = 15{,}000 \text{ amperes} \quad (18)$$

$$\text{Copper section} = \frac{15{,}000}{3{,}200} = 4.68 \text{ square inches} \quad (19)$$

The secondary winding will be one-half

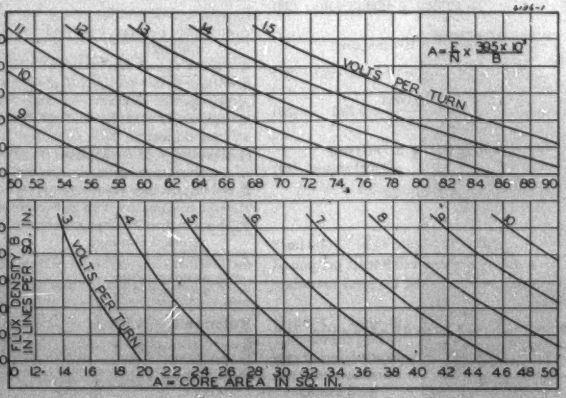

Figure 1. Core area versus flux density

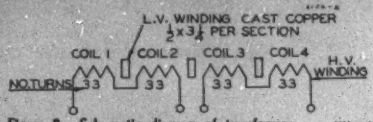

Figure 2. Schematic diagram of transformer winding

0.075×0.625 copper per turn
0.020×0.687 mica between turns

Weight = [(19¹/₄×10⁷/₈) − (7¹/₂×5)]× 5⁷/₈×0.241 = 242 pounds

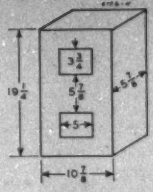

Figure 4. Detail of core

inch wide per sec ion. The area per section = 4.68/3 = 1.56 square inch.

Height of section = 1.56 ÷ 1/2, or 3.12 inches.

Leakage Reactance*

Coil 1 (With Secondary Winding on One Side)[1]

$$L = 3.2 \times T_1^2 \times \frac{MT}{l}\left(S + \frac{d_1+d_2}{3}\right)10^{-8} \quad (20)$$

$$= 3.2 \times (33)^2 \times \frac{37}{3.25}\left(0.125 + \frac{0.625+0.500}{3}\right)10^{-8}$$

$$= 39{,}700 \times 0.500 \times 10^{-8} = 19{,}850 \times 10^{-8} \text{ henries}$$

Coil 2 (With Secondary Winding on Each Side)

$$L = 3.2 \times T_1^2 \times \frac{MT}{l}\left(S + \frac{d_1+d_2}{6}\right)10^{-8} \quad (21)$$

$$= 39{,}700 \times 0.3125 \times 10^{-8} = 12{,}406 \times 10^{-8} \text{ henries}$$

Total L for coils 1 and 2
$= (19{,}850 + 12{,}406)16^{-8} = 32{,}256 \times 10^{-8}$

Total L for transformer $= \frac{32{,}256 \times 10^{-8}}{2}$

$= 16{,}128 \times 10^{-4}$ henries

$$X_L = 2\pi f L = 377 \times 16{,}128 \times 10^{-8} = 0.0608 \text{ ohm} \quad (22)$$

Primary Winding Resistance

Mean turn = 37 inches = l_1
Number of turns per coil = 33 = T_1
Area of copper = $(0.075 \times 0.625)(10)^2 \times 1.27 = 59{,}500$ circular mils

$$R_p = \frac{\rho_1 l_1 T_1}{A \times 12} = \frac{10.37 \times 37 \times 33}{59{,}500 \times 12} = 0.0177 \text{ ohm} \quad (23)$$

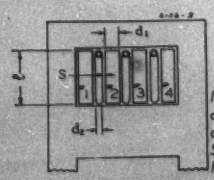

Figure 3. Detail of coil arrangement

Resistance of two coils in series
$= 2 \times 0.0177 = 0.0354$ ohm

Resistance of series-parallel winding
$= \frac{0.0354}{2} = 0.0177$ ohm

$\rho_1 = 10.37$ ohms per circular-mil foot

Secondary Winding Resistance 85 Per Cent Conductivity

Mean turn = 37 inches = l_1
$A = 1/4 \times 3^1/4 \times 3 = 4.87$ square inches
$= 6{,}190{,}000$ circular mils

$$R_s = \frac{\rho_2 l_1}{A \times 12} = \frac{10.37 \times 37}{0.85 \times 12 \times 6{,}190{,}000} = 6.08 \times 10^{-8} \text{ ohms} \quad (24)$$

$\rho_2 = \frac{10.37}{0.85}$ ohms per circular-mil foot

(cast copper)

Equivalent Resistance Referred To Primary Winding

$$R_{eq} = 0.0177 + \left(\frac{66}{1}\right)^2 6.08 \times 10^{-8}$$

$$= 0.0177 + 0.0265 = 0.0442 \text{ ohm}$$

Equivalent a-c resistance (caused by skin effect) = $1^1/2 \times 0.0442 = 0.0663$ ohm

$$Z_p = \sqrt{R_{eq}^2 + X_L^2} = \sqrt{(0.0663)^2 + (0.0608)^2} = 0.09 \text{ ohm} \quad (25)$$

$I_p Z_p$ at rated current of 227 A
$= 227 \times 0.09 = 20.43$ volts (26)

Per cent $Z_p = \frac{20.43}{440} \times 100$ per cent
$= 4.64$ per cent (27)

Power factor $= \frac{R_{eq}}{Z_p} = \frac{0.0663}{0.09} = 0.736$ (28)

I^2R loss at rated load $= (227)^2 0.0663$
$= 3{,}420$ watts (29)

Core Loss

Core loss (note Figure 4) at 77,000 lines per square inch equals 0.9 watt per pound from curves furnished by steel manufacturers.

Total core loss $= 242 \times 0.9 = 218$ watts (30)

Total loss $= 3{,}420 + 218 = 3{,}638$ watts (31)

* See Figure 3.

Efficiency at rated load $= \frac{100{,}000}{100{,}000 + 3{,}638} = 0.965$ (32)

Summary

1. Flux densities may be higher than those used in power and distribution transformers.

2. Losses caused by exciting currents have little effect on the over-all efficiency of the welding unit.

3. Losses can be minimized by the use of narrow sections.

4. Variations from optimum conditions can be made without serious effect on over-all efficiency.

5. Pancake type windings are the most efficient for resistance welding transformers.

6. Economics dictate the design of welding transformers having from three to five per cent impedance. The benefits of lower impedance transformers are offset by a greater manufacturing cost.

7. Although no mention has been made of transformers designed for frequencies other than 60 cycles, the same procedure may be followed once the proper flux density is determined.

8. The use of better insulating materials in the future will have a definite effect on present design constants.

Nomenclature

E = volts
N = turns
f = frequency
K = stacking factor
B = flux density in lines per square inch
A = area in square inches
E_0 = open circuit volts of low voltage winding
I_s = current in low voltage winding
I_p = current in high voltage winding
L = inductance in henries
T_1 = turns in each high voltage coil
MT = mean turn
l = height of high voltage coil in inches
S = distance between high and low voltage windings
d_1 = width of each high voltage coil in inches
d_2 = width of low voltage coil in inches
X_L = inductive reactance in ohms
ρ_1 = resistivity of copper in ohms per circular mil foot
ρ_2 = resistivity of cast copper in ohms per circular mil foot
R_s = d-c resistance of low voltage winding
R_p = d-c resistance of high voltage winding
R_{eq} = equivalent resistance referred to the primary winding
Z_p = effective impedance referred to the primary winding

Reference

1. Electrical Machine Design (book), Alexander Gray. McGraw-Hill Book Company, New York, N. Y., 1918, page 445.

4,370,000-Kva Short-Circuit Tests on Grand Coulee 230-Kv Bus

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Synopsis: The unusually large concentration of generating capacity at Coulee Dam makes possible short-circuit power on the 230-kv bus considerably in excess of the rupturing capacity of circuit breakers now available at that voltage. Methods of sectionalizing the bus and segregating the transmission lines to limit the maximum short circuit to less than 3,500,000 kva are described in this paper. A group of fault tests on one of the 230-kv 3-cycle 3,500,000-kva steel tank oil circuit breakers was made with a maximum of six generators connected. Three-phase faults close to the breaker rating and single phase-to-ground short-circuit currents equivalent to 4,370,000-kva 3-phase were cleared with no apparent effort by the breaker. These are believed to be the heaviest short circuits ever interrupted on any power system in the world.

THE GRAND COULEE DAM and power plant is situated on the Columbia River approximately 100 miles west of the city of Spokane, in the heart of the state of Washington. At this point on the river the mean annual runoff is 79,000,000 acre-feet, the mean annual flow is 109,000 second-feet, and the dam provides a mean hydraulic head of 330 feet for operation of the turbines. The power plant is near the center of the vast transmission network of the Northwest Power Pool, which includes 11 major interconnected private and government-owned systems operating in the states of Washington, Oregon, Idaho, Montana, and Utah.

The ultimate power plant installation is to consist of two similar powerhouses, on either side of the river, each housing nine units of 108,000-kw capacity, or a combined total capacity of nearly 2,000,000 kw. The immense size of these waterwheel generators, the largest in service anywhere, is indicated by Figure 1 showing one of the rotors being lowered into place. Associated with the power plant development is an irrigation pumping plant which is situated immediately upstream from the west powerhouse and dam abutment. This pumping development ultimately will consist of 12 65,000-horsepower pumps which will lift the waters of Lake Roosevelt to an irrigation system in the Columbia Basin. Operation of these 12 pumps will be from the first six main unit generators, *L*-1 to *L*-6, through six 5,000-ampere 13.8-kv busses. Because of provisions being made for considerable water storage in the canal system, it will be possible to use these first six generating units for pumping purposes during off-peak load periods, and for commercial load at other times. Figure 2 shows a single-line diagram of the west power plant only, with dotted lines indicating the pump installations.

Such a large concentration of generating capacity introduces unique problems in circuit breaker application and requires special switching arrangements to keep the breaker duty within the rated interrupting capacity. The high speed 3-cycle 230-kv breakers on all outgoing line positions at Coulee Dam have an interrupting rating of 3,500,000 kva, and the 8-cycle generator breakers have an interrupting rating of 2,500,000 kva. The maximum interrupting rating available at the time these breakers were purchased was 2,500,000 kva. The line position breakers subsequently were rebuilt to 3,500,000 kva when interrupters of this increased rating became available.

The power plant installation at the time the fault tests were made in December 1945 consisted of six permanent 108,000-kw units and two smaller 75,000-kw units which had been borrowed temporarily from Shasta Dam, California Central Valley Project, to augment the capacity at Coulee Dam during the war. System calculations of short-circuit currents during a line fault immediately adjacent to the Coulee switchyard indicated that the 3-cycle breaker rating of 3,500,000 kva can be exceeded if more than four units and three lines are connected to the faulted section at any one time. Because of this consideration, it was deemed inadvisable to operate with more than four units on a bus section, and since an adequate synchronizing tie is necessary between the two bus sections for system stability, the interleaved scheme of operation was adopted. Figure 3 shows a simplified diagram of the interleaved line and bus arrangement showing the synchronizing ties provided by parallel line operation to the three load centers: Spokane, Midway, and Columbia. It is not the purpose of this paper to discuss in detail the interleaved scheme and its relation to system stability on the Bonneville Power Administration system, as this was presented previously.[1] However, it should be pointed out that circuit breaker capacity may dictate to a large extent the switching arrangement and method of operation on high capacity systems.

For an example of how limitations in circuit breaker capacity affect switching operations and station capacity, let us suppose that it is desired to overhaul a generator breaker, thus making it necessary to transfer the corresponding unit to

Figure 1. Rotor of 108,000-kva generator being lowered into place at Grand Coulee Dam

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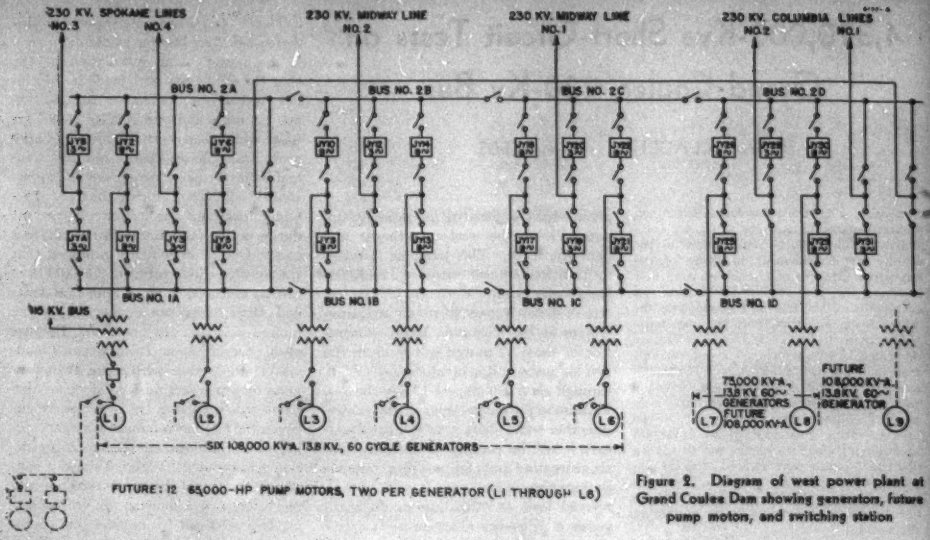

Figure 2. Diagram of west power plant at Grand Coulee Dam showing generators, future pump motors, and switching station

the opposite bus. The first operation would be to unload the unit and open the generator breaker. Before the unit can be placed on the opposite bus, however, a unit on the second bus also must be unloaded and removed from the bus as five units would exceed the interrupting rating of the breakers. This operation requires that 25 per cent of the present plant capacity, or a possible 216,000 kw of capacity must be removed from the system to accomplish the desired switching. Breakers of 5,000,000 kva capacity would make it unnecessary to remove more than one unit at a time.[3]

Fast relaying and circuit interruption during faults play an extremely important role in system stability where there are large concentrations of generating capacity and transmission lines that are heavily loaded. This is accentuated on the system under discussion by the fact that there are lumped loads and lumped generating capacity in the Pacific Northwest, separated by long transmission distances. With over 400,000 kw of generating capacity on one bus at Coulee Dam, a fault on or adjacent to this bus is a major consideration, and will result most surely in a major out-of-step condition on the rest of the system if not cleared promptly. For this reason the fastest circuit breakers available (3-cycle interrupting time) combined with the fastest system of relaying (carrier relaying) is used on the Bonneville System and at Grand Coulee to insure minimum disturbance and maximum stability.

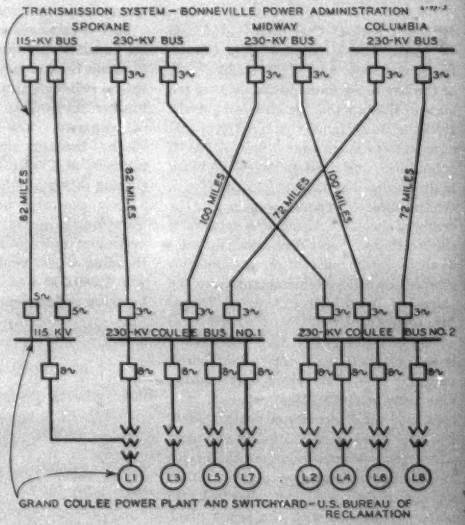

Figure 3. Simplified diagram of interleaved bus arrangement with bus ties through lines to distant stations

The 230-Kv 3-Cycle Oil Circuit Breakers

The principal design features of the 230-kv 3-cycle oil circuit breakers of the type used for the fault tests already have been described.[3] Figure 4 shows a photograph of the test breaker *JYA* which is located at the east end of the 230-kv switchyard and is used for switching one of the lines to Spokane.

The housing on the side of the first tank encloses a compressed air operating

mechanism with tripfree mechanical linkage which is capable of closing the breaker in approximately one-third second using an air pressure of 275 pounds per square inch. The high speed triple latch assembly permits the breaker to part contacts within $1^1/_2$ cycles after energizing the trip coil.

In order to obtain the maximum short-circuit current at the instant of contact parting during this particular series of tests, a special tripping switch was attached to the mechanism frame in such a position that the main lever would close the switch contacts about a cycle before the breaker contacts touched during the closing stroke. This switch can be seen in the close-up view of the mechanism in Figure 5. Thus, when closing against a fault, tripping could be initiated sufficiently in advance of the establishment of the short circuit that the contacts would separate during the first half cycle of fault current.

Each phase of the breaker is built in a steel tank, 108 inches in diameter, with capacitor type bushings having potential taps which were used to obtain an oscillographic record of the transient voltages during the breaker operation. The cross section view of Figure 6 through one of the breaker pole units shows the linkage for operating the main lift rod and cross-arm bridging the two interrupting units on the ends of the capacitor bushings.

A sectional view of the multiflow deion grid type of interrupter used in these 3,500,000-kva circuit breakers is shown in Figure 7. The effectiveness of this device is indicated by the fact that only one pressure generating break and one interrupting break per breaker terminal is required for 3-cycle operation at 230 kv. Gas pressure developed in the upper chamber by the short-circuit current sends a flow of oil down two parallel channels and then through pairs of inlets in order to converge on the main arc from opposite directions at four different levels. The flow sweeps axially upward and downward through orifice openings to the vent passages interspersed between the inlets, cooling and deionizing the arc space so that interruption takes place at an early current zero. Arc energy is kept low by avoiding unnecessary lengthening of the arc.

To supplement the self-generated flow during the interruption of line charging current, a spring driven piston is located in the bottom of the contact assembly in such a way as to operate independently of the movement of the lower contact. Oil flow from this piston passes through channels to a single orifice in the top pressure gap and then down the main channels to the interrupting break. During high current interruptions, back pressure holds the piston until after arc extinction. As the pressure falls the piston then completes its stroke, sending a flushing flow of oil through the structure.

A view of two of these multiflow deion grids taken out of the test breaker is illustrated by Figure 8. The shields have been removed to show the contact operating linkage and the vent openings in the side of the grid assembly.

Line Dropping Tests

A series of line dropping tests was made with breaker *JY*-31 opening the charging current of the 183 miles of line from Coulee Dam through Columbia substation to Covington near Seattle. On some of the tests there were single delayed arc reignitions, but the majority of operations were without any restrikes as illustrated by Figure 9, showing complete opening 2.8 cycles after the breaker trip coil was energized.

Of particular interest is the record of voltage E_a directly across the oil circuit breaker terminals. This was measured by means of an amplifier circuit fed from the voltage difference between the potential taps of the two capacitor type bushings on pole *A* of the test breaker. Note that the recovery voltage builds up to double peak value, and then oscillates about an axis displaced by an amount representing the trapped charge on the

Figure 5. Compressed air operating mechanism for 230-kv test breaker

Arrows point to special pretripping switch

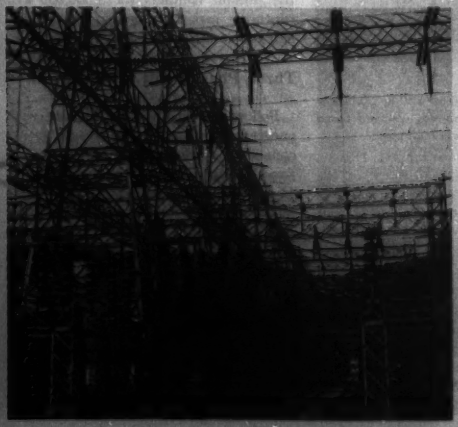

Figure 4 (left). View of Grand Coulee Dam switchyard showing 230-kv oil circuit breakers including test breaker *JYA*

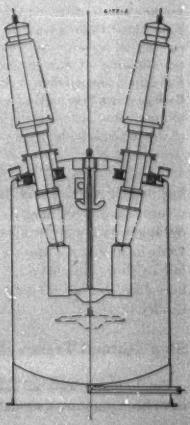

Figure 6 (right). Section through one pole of 230-kv 3-cycle breaker equipped with a pair of interrupting units rated at 3,500,000 kva

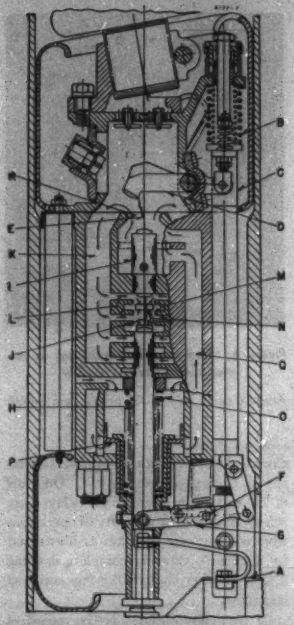

Figure 7. A 230-kv multiflow deion grid interrupting unit showing oil flow path from piston used to interrupt line charging current

Tripping of breaker releases main cross arm *A*, allowing springs *B* to move operating rod *C* down and rotate contact arm *D*, drawing pressure generating arc *E*. Simultaneously, pin *F* swings lever *G* downward, pulling contact *H* away from intermediate contact *I* to draw main arc *J*. Pressure from upper arc *E* drives oil through channels *K* to multiflow inlets *L*, deionizing arc in multiorifice structure *M*, and sending arc products out vents *N*. Springs *O* push piston *P* downward to provide supplementary oil flow for low current arc interruption, flowing oil through channel *Q* to orifice *R* in upper gap and then to main flow channel. Back pressure from high current arcs stops piston until arc is interrupted, when completion of stroke sends flushing oil flow through grid

Table I. Fault Tests—Oil Circuit Breaker *JYA*

December 2, 1945

Generating Units *L*-2, *L*-4, *L*-5, *L*-6, *L*-7, *L*-8*

Duty Cycle	Test Number	Oscillogram Number	Type of Fault	Spokane Number 4 Line Bus Voltage, Kv	Phase	Instrument Current Transformer	Bushing Current Transformer	Fault Current,‡ RMS Amps	Interrupted kva on 3-Phase Basis	Interrupting Time, Cycles
CO-15-CO	1	35	3 phase to ground	On	241.5	A	5,000/1		6,908	2,880,000	
						A		300/1	7,000	2,929,000	2.7
						B		300/1	7,425	3,106,000	2.5
						C		300/1	6,340	3,610,000	2.8
CO-15-CO	2	36	3 phase to ground	On	241.5	A	5,000/1		5,900	2,470,000	
						A		300/1	6,350	2,658,000	2.4
						B		300/1	5,940	2,485,000	2.7
						C		300/1	6,630	2,770,000	2.6
CO-15-CO	1A	40	Phase A to ground	On	241.5	A	5,000/1		6,360	2,660,000	2.5
	1B	41	Phase A to ground	On	241.5	A	5,000/1		7,840	3,280,000	2.4
CO-15-CO	2A	42	Phase C to ground	Off	241.5	C	5,000/1		10,450	4,370,000	2.7
	2B	43	Phase C to ground	Off	241.5	C		300/1	†8,866	†3,708,000	
						C	5,000/1		10,450	4,370,000	2.7
								300/1	†5,006	†2,094,000	
CO-15-CO	3A	44	Phase B to ground	On	241.5	B	5,000/1		10,015	4,190,000	2.8
								300/1	†7,311	†3,016,000	
	3B	45	Phase B to ground	On	241.5	B	5,000/1		6,535	2,735,000	2.7
								300/1	†6,677	†2,793,000	

* See Figure 10 for bussing arrangement.

† These current values are not reliable because of saturation of the 300/1-ampere bushing current transformers. The 5,000/1-ampere instrument current transformer has a 5,000-ampere primary rating, with a 1-ampere secondary.

‡ These currents are not necessarily the maximum fault currents obtained, but are the currents existing at the instant of mechanical separation of the breaker contacts, upon which the interrupted kva is based.

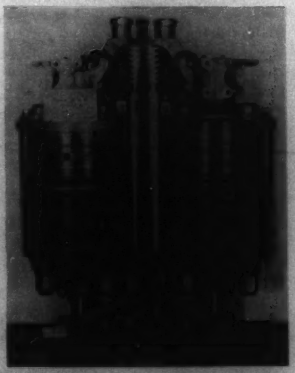

Figure 8. View of pair of 230-kv multiflow deion grid units with shields removed taken after high power fault tests

line which very slowly leaks off. The records of line voltage E_s and E_c, being obtained with conventional potential devices including a step-down transformer, fail to show the sustained charge on the line after being disconnected from the Coulee bus.

Short-Circuit Tests

Single phase tests at 132 kv to ground have been made on a similar breaker in the high power laboratory up to 10,400 amperes, corresponding to a 3-phase fault of 4,300,000 kva. The rate of rise of recovery voltage on this freely oscillating laboratory circuit is approximately 2,500 volts per microsecond, representing a more severe operating condition than is ever likely to be encountered in service.

The 230-kv bus at Coulee Dam, when all transmission lines are disconnected, approximates the laboratory conditions, although it is not likely that maximum generating capacity would be connected to a bus section with only one line carrying load. However, there is more capacitance to ground on the Coulee bus than a laboratory circuit because of the greater number of connected pieces of equipment such as breakers, transformers, bus supports, and coupling capacitors. This is sufficient to reduce the natural frequency of oscillation at the bus, and likewise the voltage recovery rate, to less than 40 per cent of the laboratory circuit.

It should be pointed out that although test breaker *JYA* has been in service for about four years, it was revamped with the present contacts for 3,500,000 kva rupturing capacity about a year and a half before these special tests.

Three-Phase Fault Tests

Following two preliminary tests with one generator and with three generators connected, a standard duty cycle test of two close-open operations separated by a 15-second interval was made under a 3-phase grounded-fault condition with six generators connected. These included four 108,000-kva units and the two 75,000-kva generators as shown in Figure 10. The maximum power interrupted, as indicated by the data of Table I for tests 1 and 2, was 3,100,000 kva, approximately 89 per cent of the breaker rating. The breaker was pretripped as described, permitting the contacts to be separated during the first cycle of short-circuit

Figure 9. Oscillogram of interruption of charging current to 183 miles of 230-kv line

Record E_a through amplifier shows voltage across pole 1 displaced by charge on line

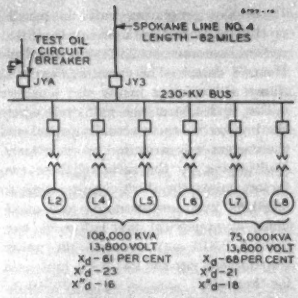

Figure 10. Diagram of connections for short-circuit tests on 230-kv 3-cycle breaker *JYA* using four 108,000-kva generators and two 75,000-kva units in parallel

current (see Figure 11). The performance of the breaker was remarkably quiet, no smoke or jar being evident to the observers.

Before proceeding with the single-phase short circuits at current values up to and above the breaker rating, the oil was removed and an inspection made of the condition of the contacts. So little material was burned away that it was not considered necessary even to smooth up the contact surfaces or make any changes in the contact adjustments. The oil and insulating surfaces were quite clean, so that the breaker was refilled immediately for the remaining tests.

Single-Phase Fault Tests

Each pole of the breaker was given the standard duty-cycle test consisting of two close-open operations separated by a 15-second interval, with a single line-to-ground fault close to the breaker and six generators feeding power to the bus. The pretripping scheme was used again to obtain contact parting as close to the first cycle as possible. Data from the oscillograms of these six interruptions also are given in Table I.

Tests 2*A* and 2*B* form a remarkable pair of almost duplicate interruptions of 10,450 amperes at 241.5 kv bus voltage, corresponding to 4,370,000 kva on a 3-phase basis. The breaker trip coil was energized one cycle before the closing contacts established the fault current which consisted of only three half waves, two large almost completely displaced loops with a small reverse loop between (see Figure 12). The breaker performed quite easily on all of these high power operations, there being very little external evidence of the tremendous short-circuit power cleared by the switch. Since no transmission lines were connected during these two tests, the bus voltage was permitted to oscillate freely, giving a voltage recovery rate estimated from the oscillograms to be close to 1,000 volts per microsecond.

It is interesting to compare the short-circuit current values actually measured with the calculated figures. The maximum asymmetrical 3-phase short-circuit power from four 108,000-kva and two

Figure 11. Oscillogram of 3-phase short-circuit test at 241.5 kv interrupting 3,100,000 kva

Breaker pretripped one cycle before fault established by closing contacts

75,000-kva generating units in parallel on the 230-kv bus, with two cycles of decrement, amounts to 2,970,000 kva from Hoard's data.[1] The curve in Figure 13 shows a decrement factor of 1.4 at two cycles, and 1.64 at one half cycle where the breaker contacts actually parted and the current was measured on these tests. Multiplying by the ratio of these two factors raises the short-circuit power to 3,480,000 kva, corresponding to a maximum asymmetrical first-half-cycle current of 8,310 amperes with the power transformers on the 241.5-kv taps used for the tests.

For single-phase faults, with all of the transformer neutrals solidly grounded, the current should be at least 30 per cent higher or 10,800 amperes, which is approximately the maximum current obtained.

On the other four interruptions, the same six generators were connected, but varying degrees of asymmetry in the current wave resulted in short-circuit power between 2,500,000 and 4,000,000 kva on a 3-phase basis. For these tests Spokane number 4 line, 82 miles long, was connected to the high voltage bus, cutting the voltage recovery rate to about a third and damping out overswinging of the initial transient. No consistent effect on the interrupting performance was observed, however, because of this difference in recovery rate, the interrupting times on the six high-power single phase tests being included in the narrow range from 2.4 to 2.8 cycles with an average of 2.65 cycles.

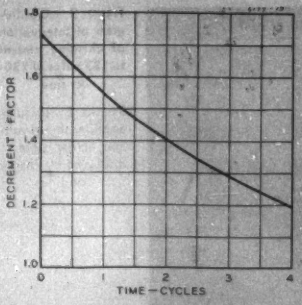

Figure 13. Calculated decrement of maximum asymmetrical fault current for short circuit at Grand Coulee 230-kv bus

Test values checked this curve very closely

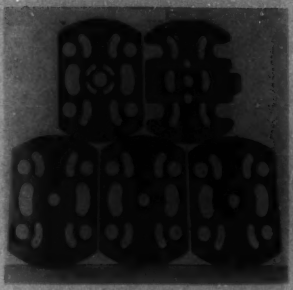

Figure 14. Photograph of fiber grid plates removed from multiflow grid after 4,370,000-kva test showing only slight erosion of orifices

Small chip of fiber was split off upper right plate

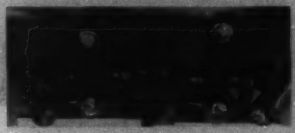

Figure 15. Photograph of arcing contacts from pole 2 of 230-kv breaker after 4,370,000-kva test showing only moderate burning of silver-tungsten tips

The oil dielectric strength after this heavy duty measured as high as before the tests, and there was only a slight discoloration caused by carbon formation from the arcing. All of the multiflow grid surfaces were quite clean, with no appreciable enlargement of the orifice dimensions as indicated by Figure 14. The silver-tungsten contact tips had lost not more than $^1/_{32}$ inch of material over only a part of the surface area, and were still in condition for further service (see Figure 15). The only result of applying these heavy short circuits up to nearly 25 per cent above rating was the cracking off of a small sliver from one of the fiber plate items, and a dislodgement of one intermediate contact sufficient to keep it from falling back into its normal position. With minor design changes to increase the mechanical ruggedness still further there would seem to be no reason why this type of interrupter could not handle satisfactorily short circuits of 5,000,000 kva.

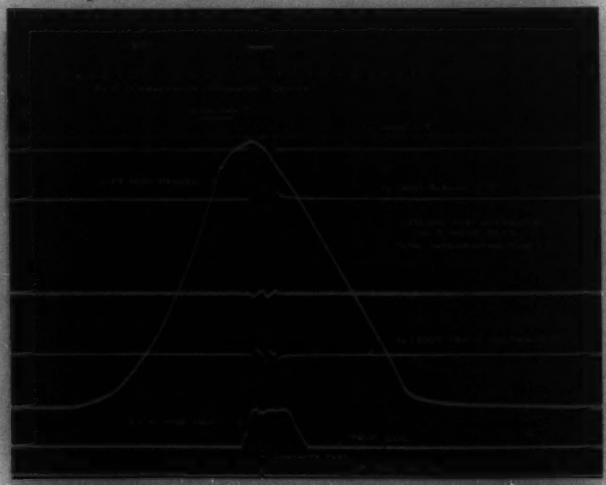

Figure 12. Oscillogram of maximum power single-phase fault interruption, equivalent to 4,370,000 kva at 241.5 kv 3-phase, within 2.7 cycles after energizing breaker trip

No lines connected to bus

Conclusions

These heavy short-circuit tests above 4,000,000 kva on the 230-kv bus at Coulee Dam have served not only as a check on calculations of fault currents, but they also have confirmed high power laboratory test in demonstrating a margin of safety in the rupturing capacity of the 230-kv 3-cycle breakers as rebuilt for a rating of 3,500,000 kva. The relative ease with which the test breaker performed its duty suggests the practica-

Philosophy of Relaying

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PHILOSOPHICALLY the electric power system exists to serve certain human needs and it must serve them better and more economically than they could be served by other methods or it would not be able to continue to exist or to grow. The rendering of service of the required degree of excellence, within economic limitations, is not an inherent attribute of the electric power system but is the result of sustained and carefully co-ordinated effort on the part of all concerned in the rendering of the service, including

1. Precautions taken in the design of equipment to make it trouble free and reliable.

2. Precautions taken in system layout and connections to enable service to be rendered continuously under adverse as well as under favorable conditions.

3. Precautions taken in the operation and maintenance of the system to avoid unnecessary interruptions to service.

When everything economically possible has been done along these lines, however, the system still remains subject to unavoidable defects which result in faults, tending to cause damage to equipment and interruptions to service. Specific measures taken to minimize the detrimental effects of such faults comprise system protection, the fundamental idea of which is to reduce damage to equipment and to improve service to customers. Relay protection cannot prevent faults from occurring on the power system, but it is a means of minimizing the effects of such faults when they do occur. The expenditure which can be justified for protection is a measure of the probable reduction in cost of repairs and of the probable improvement to service which will result from the use of the protection.

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General Principles of Protection

The basic ideas and principles which underlie and determine the policies adhered to in providing protection for the electric power system are relatively few and simple. They may be divided conveniently into two groups.

The immediate object of the electric power system is to make continuously available a supply of energy at approximately constant voltage and frequency. A difficulty encountered in attaining this objective results from the fact that a fault at one point on the system tends not only to destroy or seriously damage the equipment directly affected but also to involve the whole system in serious voltage and frequency disturbances and possibly in widespread interruptions to service; the seriousness of these effects being, in large measure, determined by the length of time that the fault is allowed to remain on the system. This difficulty is met by building the system up of numerous elementary sections joined together at strategic points by suitable automatic circuit-interrupting devices which enable any section to be isolated from the remaining sections without interfering seriously with the essential integrity of the system as a whole. Each of these sections is then provided with appropriate automatic equipment designed to detect faults within the section and to quickly and selectively isolate a defective section from the remainder of the system. In order that no part of the system may remain unprotected the various zones of protection are made to overlap each other at the junction points of the respective sections.

Not only is system protection concerned with the successful isolation of defective sections of the system, it is concerned equally with the determination of fault locations and causes and with the return to service of affected sections in as short a time as possible. For this purpose, therefore, extensive use is made of relay indicators, automatic fault locators, and automatic oscillographs in the analysis of system troubles. Furthermore, experience has shown that the majority of faults on transmission circuits prove to be transient if they are cleared quickly. In such cases automatic reclosing breakers are used as an additional means of improving service.

From the foregoing it may be concluded that, to a very large extent, the protection of a large power system must be a custom built job. The system is analyzed carefully and whenever major modifications or additions take place the necessary fault studies are carried out. As a result of such studies appropriate protective schemes are applied. In general, these schemes are built up in the field, of standardized units of equipment, assembled into the various special combinations necessary to meet the requirements of any situation that may be encountered.

Another fairly obvious conclusion is that, in order to obtain the degree of co-ordination required for successful functioning, the protection of the whole system must be placed under the control of one centralized authority.

Applications of Principles

When attempting to apply the principles of protection it is necessary to note the physical conditions that can be made use of as the basis of the automatic features of protection. Of primary importance in this respect are the two active quantities of the electric circuit—current and voltage. Intelligently used in appropriate circuits and devices they can be made to represent most of the characteristics that are essential in distinguishing between normal and abnormal conditions on the system. To a more limited extent, various other physical conditions associated with electrical apparatus such as temperature, pressure, gas accumulation, and frequency, may be used also. In addbility of constructing breakers of still higher interrupting rating. The application of such breakers at Coulee Dam would free the system from present operating limitations.

The success of these record breaking tests is the result in no small measure of the excellent co-operation of many members of the engineering and operating personnel of the Bureau of Reclamation, Bonneville Power Administration, and Westinghouse Electric Corporation.

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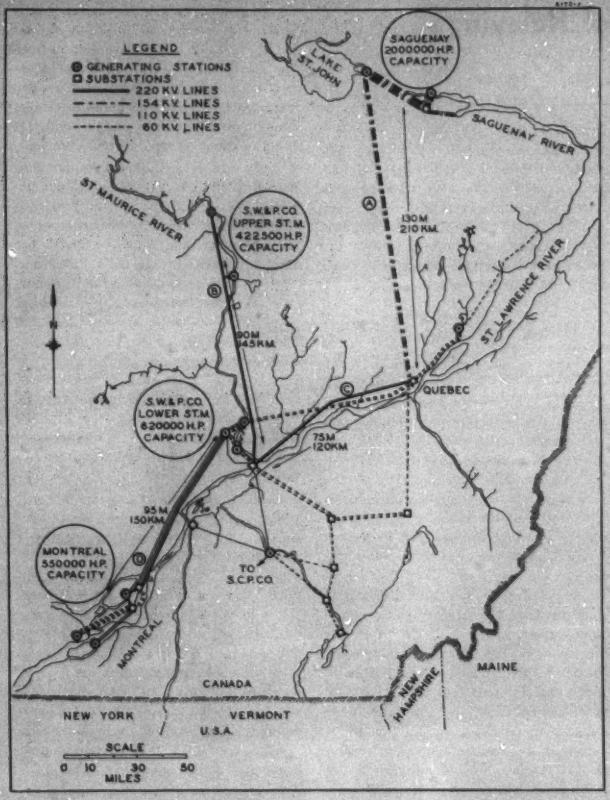

Figure 1. Map showing main transmission lines of interconnected systems, Province of Quebec

dition to these, time is quite generally useful as a co-ordinating factor.

Protection may be considered to be simple or complex depending on whether it makes simultaneous use of one or more of the fundamental quantities available for fault detection. Furthermore, complex protections may possess varying degrees of complexity.

The simplest form of protection is the fuse which utilizes current only and finds extensive applications on a great variety of electric circuits from the lowest voltages up to 138,000 volts. It incorporates in itself both the fault detecting and circuit-interrupting functions. Its great advantages are low cost and simplicity, but its use is limited to circuits carrying a few hundred amperes. An outstanding disadvantage is the more or less prolonged interruption to service required for replacement whenever there is an operation. This may be overcome to some extent by application of the principle of the reclosing fuse. Their somewhat inflexible time–current characteristics may at times be another disadvantage of fuses.

Some of the limitations of fuses may be overcome by utilizing electromagnetic coils energized by the current flowing in the protected circuit. It is then necessary to provide a separate circuit-interrupting device, or circuit breaker, which the coils may actuate. The simplest form of protection associated with a circuit breaker consists of a trip coil on the breaker actuated by the current, or a proportion of the current, which passes through the breaker. Such trip coils may be provided with dash pots to give them an adjustable inverse time–current characteristic. A means is then available for obtaining selective action between circuits on a system so protected. The flexibility of this form of protection may be increased by separating the adjustment and timing features from the trip coil and incorporating them in relays, leaving the trip coil the sole duty of releasing the latch on the circuit breaker.

In these simple forms of current protection there are only two possibilites of obtaining selectivity. One is the possibility that the relative magnitudes of fault currents, at the points between which selectivity is required, will differ by a sufficient amount to inherently provide the required selectivity. The other is the possibility of using time to provide the required selectivity. The former possibility is usually a forlorn hope. The great disadvantage of the latter is the delay involved in clearing faults, which may become several seconds on an extensive system. Another disadvantage is the fact that, in obtaining selectivity by timing, the shortest clearing times are at the ends of branch feeders where fault currents are minimum whereas, from the point of view of limiting damage, the shortest clearing times should be nearest to the power source where fault currents are maximum. Even accepting the kind of selectivity that can be obtained by the use of time and simple current, the method is applicable to radial systems only and not at all to networks.

The field of usefulness of protective features based on current only may be extended very appreciably by associating with it the principle of comparison. This gives rise to such schemes as:

1. Differential current which may be applied to transformers, generators, busses, and short tie lines. Advantages of differential current protections are the fact that the zones protected are clearly and sharply defined providing inherent selectivity; settings may be very sensitive and time instantaneous. Such protections involve problems of current transformer characteristics.

2. Current balance protections such as parallel line and generator split phase. An advantage of the split phase protection is that it can be made very sensitive. Its zone of effectiveness is also clearly defined. Parallel line protections are ineffective for line end faults. On radial lines the zone of ineffectiveness may be a considerable percentage of the line length.

3. Phase sequence networks actuated by current only may be used in conjunction with pilot wires to provide current comparison between the two ends of a transmission line, giving the equivalent of a differential protection.

4. Another method of protecting transmission lines by means of current only is to utilize phase sequence networks in conjunction with carrier current to compare the relative directions of current flow at the two ends of the line.[4]

Also included in the simple protections are

1. Overvoltage, used on generators.
2. Residual voltage, for generator neutrals.
3. Undervoltage.
4. Unbalanced voltage.
5. Gas accumulation, used on transformers.
6. Pressure, used on transformers.
7. Temperature, used on various kinds of equipment.
8. Overfrequency.
9. Underfrequency.

Among the complex protections, impedance is probably the simplest. In principle it uses current and voltage to measure the impedance to a point of fault. When the impedance drops below a critical value operation results. It has the advantage that its distance range, or zone of effectiveness, may be limited at will, within reason. It has the further advantage that it is most sensitive for near-by faults and increasingly insensitive as the end of its zone of effectiveness is approached. Its field of usefulness is in the protection of lines, especially on networks, and for standby or backup protection. It has the disadvantage that its range is altered by power arc voltage and by fault resistance. By associating it with a single time-step effective co-ordination of the protection on a radial system may be obtained without an inordinate increase in time of clearing faults at any point. On network systems it may be associated with directional features of protection to attain an effective co-ordination of the protection of the whole network. In cases where changes of generator capacity connected to the system would affect a simple current protection this limitation is not found with impedance protection.

The disadvantage of having the distance range of an impedance relay affected by fault resistance can be overcome by using a reactance relay. If necessary to attain selectivity a directional impedance or reactance protection may be combined with pilot features by using direct current on metallic conductors or by using carrier on the high voltage line. Under this condition the distance range adjustment need not be critical and simultaneous clearing of both line ends is obtained for all line faults.

On long heavily loaded lines impedance relays may get into trouble by tripping on overload or on power swings. Such a condition may be improved by the use of relays which measure impedance at an angle.

When sections of a large power system tend to pull out of synchronism due to clearing faults, power surges over certain tie lines may cause unnecessary tripping. In such cases when there is the probability that the swings would subside and conditions return to normal, out-of-step blocking may be added to protections that are sensitive to these conditions, to prevent faulty tripping. In cases where it is probable that synchronism cannot be maintained after a swing starts, conditions can sometimes be improved by separating the system at a selected point. For this purpose a system separator can be added to the appropriate protection.

The protective features discussed thus far have been those designed to detect and selectively isolate faults. There remains to be considered, methods of automatically returning circuits to service following the isolation of a fault. In general automatic reclosing is not applicable in the case of equipment failures because defective equipment requires inspection and repair before it can be returned to service. On lines and feeders however the majority of faults are transient and the circuit will remain in service if reclosed immediately. With high speed protection should reclosing take place onto a permanent fault no particular harm would result.

A successful scheme of automatic reclosing can be based on the principle that if a fault is transient the circuit will stay in if it is reclosed immediately after it has cleared. If a fault is permanent the circuit will trip again immediately after it has been reclosed and no further attempts at reclosing should be made. There does not appear to be any practical use in providing more than a single shot recloser. In practice such a recloser is built to lock-out should the circuit to which it is applied trip twice within a predetermined time interval, which may be anything from about 2 to 15 or more seconds.

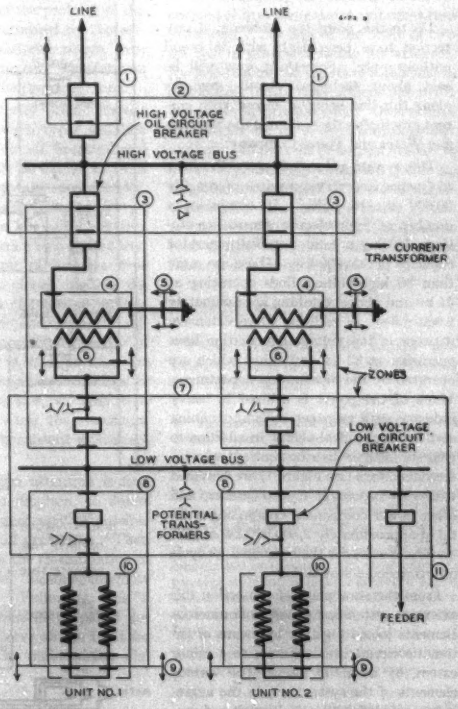

Figure 2. Diagram showing how a power system is covered by overlapping zones of relay protection

Number	Protection
1	Line
2	High voltage bus
3	Transformer differential
4	Transformer high voltage ground differential
5	Transformer high voltage ground stand-by
6	Transformer stand-by
7	Low voltage bus
8	Generator differential
9	Generator stand-by
10	Generator split phase
11	Feeder

Circuit breaker duty ratings have a bearing on automatic reclosing. If circuit breakers have ample capacity the time allowed for resetting the recloser may be short, if not the time must be longer.

Another factor which must be considered in providing automatic reclosing is the condition of synchronism. If a line is a tie between systems it must be decided whether to permit reclosing out-of-phase to take place, depending on the systems to pull into step, or to provide an automatic synchronizer, to operate in conjunction with the automatic recloser.

Practical Aspects of the Art of Protection

Up to this point the problems of protection have been dealt with in broad outlines only. Something now will be said about technical details, remarks along this line being in accord with current practice on the system of the Shawinigan Water and Power Company.

This system is located in the Province of Quebec and serves an area of roughly 30,000 square miles. It comprises a number of hydroelectric generating stations, having a total installed generator capacity of 830,000 kw. There are more than 60 high-voltage lines operating at 44 kv and above, totalling approximately 2,000 miles; in addition to an extensive network of low-voltage distribution lines operating at 33 kv and below which are operated by the distribution department. Much of the power is utilized in heavy industry such as paper mills and mining and electrochemical plants, in addition to that supplied to distribution centers. Interconnections (see Figure 1) are provided with the Saguenay, Hydro-Quebec, and other power companies, comprising a total of approximately 2,500,000 kw of generator capacity for the combined 60-cycle interconnected system.[3]

From the standpoint of protection this extensive system is composed of numerous elements joined together by means of automatic circuit breakers and, to a minor extent, by means of fuses. The various elements of the system are, in the aggregate, provided with a multiplicity of protective schemes which require the use of approximately 10,000 relays of 300 types. As far as possible each element of the system is provided with a protection, the zone of effectiveness of which overlaps the protected zones of adjacent elements. For convenience, relay protection zone diagrams are provided for the various sections of the system. Figure 2 is such a diagram for a small section of the system. This diagram depicts all the main elements of the system, namely, generators, transformers, busses, lines, and feeders; and may be used conveniently as the basis of a discussion of some practical details of protection design.

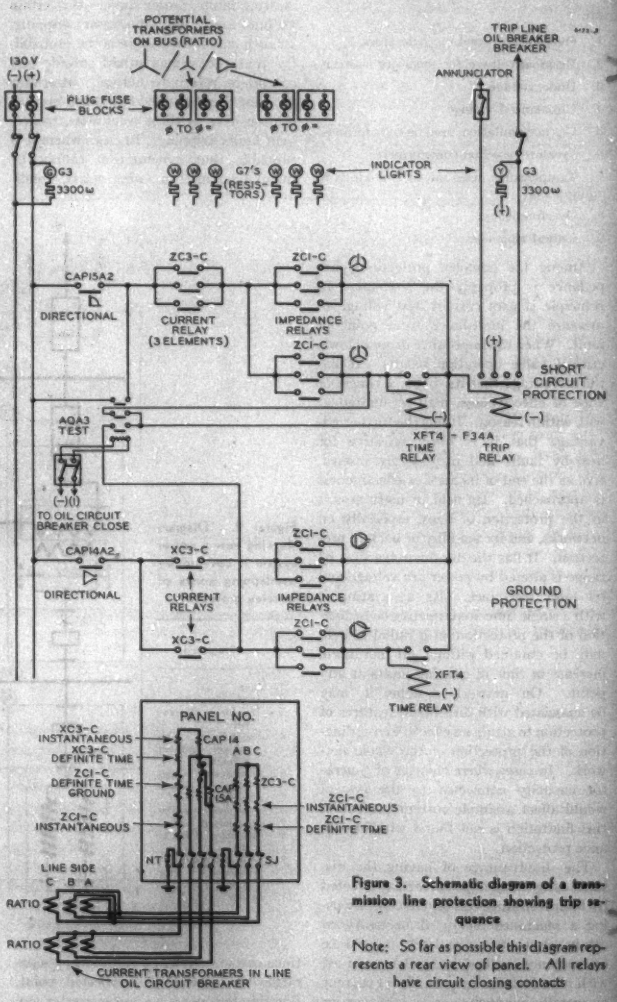

Figure 3. Schematic diagram of a transmission line protection showing trip sequence

Note: So far as possible this diagram represents a rear view of panel. All relays have circuit closing contacts

The hypothetical section of system shown in Figure 2 is more liberally provided with circuit breakers than is often the case in practice. In some of the older generating stations a main low voltage bus has been provided, but in stations constructed during the past 20 years the tendency is to operate a unit system, each generator and its associated power transformer forming the unit. In some stations transformer banks are not provided with high voltage circuit breakers. High voltage lines, also, sometimes are not provided with high voltage circuit breakers. In all these cases the best expedients available are adopted to make the protection as effective as circum-

stances permit. One of these expedients is the high voltage fuse for transformer protection.

In general high voltage fuses are used on power distribution transformers and on potential transformers. It was formerly the practice to install glass-enclosed lead fuses on small and medium capacity transformers. In case of faults above the rupturing capacity of these fuses, the fault would be transferred to the high voltage line, causing it to open automatically by the action of its protection. Recent practice is to provide fuses of suitable timing characteristics and ample rupturing capacity for the respective location. Both dry and liquid types of fuses are used but preference is now given to the dry types because of their greater convenience and economy in use. Timing characteristics include: high speed fuses for potential transformers and for distribution transformers where selectivity is not required or where selectivity requires fast clearing; medium speed fuses where required for selectivity with other fuses or very fast circuit breakers; and slow acting fuses where selectivity is required with slow operating circuit breakers and relay protection. Fuses should only be used where it is not economically possible to justify the installation of an adequate relay protection.

Where high voltage fuses do not provide an adequate protection and where it is not possible to justify the installation of an automatic circuit breaker automatic grounding switches are used. The operation of the relay protection initiates the closing of the ground switch and this in turn permits the respective main line to be cleared by the action of its protection. Single-pole, 2-pole, and 3-pole switches are in use, either spring operated or motor operated. Experience has indicated that the motor mechanism is more reliable than the spring and that a 2-pole switch is usually adequate.

Protective relays are energized in general by current and potential transformers. Recent practice has been to utilize, as far as possible, bus potential transformers for line relay protection up to and including 110 kv. On systems operating at voltages above 110 kv either capacitor-type potential devices or compensated low voltage potential transformers are used for line relaying. Potential transformers are commonly provided with double secondaries to facilitate obtaining a delta point voltage for ground protection when required. When such a voltage is required and the potential transformers have only one secondary a set of one-to-one ratio auxiliary potential transformers may furnish the required voltage. Occasions also may arise where auxiliary potential transformers furnish a convenient means of correcting phase angle or ratio in the potential supply.

Current transformers quite commonly define the limits of protective zones. This is particularly true in the case of differential protections, but an exception may be noted where a feeder carrying a small load is permitted as a leak in the differential zone. Various justifications may be found for this practice, such as lack of suitable circuit breakers. In the case of directional distance line protections the directional relays permit the current transformers to mark one limit of the zone of effectiveness of the protection, the other limit being determined by the setting applied to the distance relays. On pilot protections current transformers mark both limits of the protected zone.

The most extensively used current transformers are through types installed on the bushings of circuit breakers and transformer banks, or on cables and bus bars when voltages do not exceed 15 kv. Wound primary current transformers are used to some extent on low voltage circuits and on circuit breakers which do not lend themselves to the use of bushing type transformers. Some circuit breaker designs do not permit the use of built-in current transformers and separate oil-filled current transformers are used. In all cases an attempt is made to keep the resistance of the secondary windings of current transformers low, to keep lead burdens low and to use the maximum cross section of iron consistent with space limitations.

In protection design attention is first given to the system diagram, to determine what may be necessary or possible in the way of zones of protection. Then fault studies assist in the co-ordination of the various features of the complete protective scheme. Following this a trip sequence diagram is prepared for each protection, to serve as the basis for the preparation of the main wiring diagrams.

Generators

Generators of 10,000 kva capacity or above usually are provided with several features of protection, including

1. Instantaneous split phase.
2. Instantaneous current differential.
3. Definite time impedance standby.
4. Definite time or inverse time overvoltage.
5. Definite time or instantaneous ground alarm.

The ground alarm is usually provided through the medium of a single potential transformer in the generator neutral or through the installation of a set of star/corner delta potential transformers connected to the generator terminal leads. Thirty per cent of all generators are grounded through a single potential transformer.

In future installations serious consideration will be given to the installation of a small single phase distribution transformer between generator neutral and ground. Differential and split phase protections are set as sensitively as possible to reduce burning of iron laminations and thus avoid restacking. Settings of the order of two per cent of generator rating are attained. By-pass reactors on the relay coils assist in eliminating faulty relay actions due to d-c transients on through faults. Overvoltage protections are set to act instantaneously at about 140 per cent of normal voltage to avoid overstressing insulation following a sudden drop of load. The standby protection acts as a stand-by to the system protection at large and to the generator in case of the differential and split phase features are out of service.

Transformers

Power transformers are usually provided with one or more of the following forms of protection:

1. Inverse-time current differential or 2-step current differential. In some cases impedance relays are used instead of current relays for this feature.
2. Instantaneous residual current ground protection, connected differentially if it appears feasible or advantageous to do so.
3. Gas detector relay to indicate gas accumulation or pressure. In some cases the gas accumulation element is arranged to provide a visual and audible indication only, without actually tripping the respective bank.
4. Impedance stand-by, combined with generator stand-by on the unit system.

Large power transformers are usually provided with some form of differential protection, which either overlaps the generator protection, in the case of a unit system, or the low voltage and high voltage bus protections where busses are used. The aim is to make these protections as sensitive as possible to avoid damage to core iron and to reduce the hazard of oil fires.

In the 2-step form the sensitive feature is set at 30 per cent of bank rating

and 2.5 seconds definite time; the instantaneous feature is set at 225 per cent of bank rating.

Gas detector relays are used more particularly on large 3-phase power transformers and step regulators. Many 3-phase power transformers are equipped for tap changing under load and the gas detector relay provides a measure of protection for this device. Gas detector relays also are used on single phase transformers where they would be more convenient to apply than an adequate excess current or differential protection. Experience with these relays has been reasonably satisfactory and the gas detector element has operated for conditions such as low oil, air in the oil, stoppage of breathers, and overheated connections. Some difficulties have, however, been encountered because of inexperience of operating personnel, oil hammer when attempting to determine the presence of gas, and moisture collecting on the terminal studs of the relay.

Busses

Busses usually are equipped with some form of duplicate differential protection. This usually requires two current transformers per phase, unless a special arrangement is devised.

In some cases a scheme of double differential bus protection has been provided using a single set of current transformers with both impedance and current relays connected so that it requires both features to operate in order to trip the respective bus. Where fault currents exceed the interrupting capacity of low voltage circuit breakers an excess current feature may be added to the respective feeders to insure automatic clearance of the whole bus, rather than rely on the low interrupting capacity of individual circuit breakers. During recent extensions to the power system, it was estimated that fault current in the vicinity of one 110-kv station would exceed the interrupting capacity of existing circuit breakers. There were two 110-kv busses at this station and an arrangement was made to install a high speed circuit breaker between these two busses, equipped with a relay scheme to automatically open the bus tie circuit breaker for nearby faults. It is designed in this manner so that the busses will be separated before a local breaker attempts to clear a nearby fault, thereby reducing the fault current to a value which can be handled by the circuit breaker on the faulted circuit. This feature has operated on several occasions to date with satisfactory results.

Lines

Line protections vary greatly depending among other things on voltage, load, type of system, and type of line. In general the Shawinigan Water and Power Company favors the 2-step impedance and directional scheme for both short circuit and ground protections. The trip sequence diagram of such a protection is shown in Figure 3. This form of protection is particularly applicable to high voltage lines having low ground resistance and operated in either a parallel line or network system.

On lines having high ground resistance, such as wood pole lines, stand-by residual current relays are added to other features. In some cases use has been made of parallel ground relays for wood pole 60-kv lines operating in parallel at both ends. Some difficulty has been experienced in providing a fully satisfactory ground protection for such wood pole lines not equipped with overhead ground wires or other means of reducing ground fault resistance. On short tie lines connected into the main transmission network recent practice has been to provide buried counterpoise wires in order to improve the effectiveness of the impedance ground protections.

All power circuits of 110 kv and above are operated solidly grounded star. All 60-kv circuits are operated "delta isolated neutral" but with small grounding transformers located at strategic points. In some cases transformers of 1,000–3,000 kva capacity used for auxiliary supply are utilized also as grounding transformers. A circuit breaker frequently is installed in the neutral of the grounding transformer and arranged to trip automatically when grounds persist for a definite time of two to three seconds. Most of the high voltage steel-tower lines are provided with either overhead ground wires, buried counterpoise wires, or both. This tends to reduce lightning outages and to keep the ground resistance to a low value, permitting the successful use of impedance ground delays.

The instantaneous step of an impedance protection is ordinarily set to cover 95 per cent to 100 per cent of line length. The second step is set to reach into the next line section with a time delay of 0.5–0.8 second. With high speed circuit breakers and protections it is probable that selectivity can be retained with these time delays reduced to about 0.4 to 0.5 second. On 3-ended lines 3-step impedance protections have been used successfully.

Instantaneous protection over the whole length may be obtained by the use of pilot protection. Three forms are in use

1. A-c 3-wire system using low resistance conductor.
2. D-c 2-wire system using high resistance conductor.
3. Carrier current on the high voltage lines.

Outstanding disadvantages of the a-c pilot wire protection are its high cost limiting its use to very short tie lines and the fact that it does not provide inherently any stand-by or backup protection. The cost of carrier current protection limits its use to high voltage lines and to conditions where adequate protection cannot be obtained otherwise. The d-c pilot protection is used on lines up to 25 miles in length. It usually operates from dry cells of 90–135 volts rating. Conductors vary, depending on local conditions, and include private telephone circuits, leased Bell Telephone circuits, and small-conductor buried cable. All pilot cables are well insulated from ground. The d-c pilot scheme has the advantage that it can be added to a more or less standard line protection and will provide stand-by protection at all times, even when the pilot feature may be out of service.

Automatic Reclosing

There are several automatic reclosing installations in service on transmission systems operating at voltages up to 187 kv. New installations are being completed as rapidly as conveniently possible. Recent practice has been to adopt one immediate automatic reclosure with an automatic reset feature for transient faults and lock-out for permanent faults. Time delay of reclosure is normally kept to a minimum, usually not more than 2.5 seconds. To date, there are no installations of automatic reclosing on lines directly supplying synchronous motor loads. However, installations are now under consideration on a number of 60 kv lines supplying paper mill and mining loads, which include synchronous motor installations. An installation is also being completed on a system consisting of a small generator connected through a tie line to the main system, and on one of the radial lines connected to this there is a synchronous motor. We are looking forward with considerable interest to this development, with a view to extending automatic reclosing to network systems.

Conclusion

It will be realized that the application of protection to the power system does not

Control and Protection of Aircraft D-C Power Systems

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D-C POWER SYSTEMS on transport aircraft before World War II were small in capacity as compared to the present requirements. Present wide speed-range generators are 12 to 15 times the ratings used on old DC-3's, and system capacity on new transports may be 30 times greater and capable of sustaining fault currents greater than 5,000 amperes at 30 volts. It is also necessary to consider the increase in the voltage from the smaller system to the larger system. The 12-volt system does not have sufficient potential to maintain an arc or ionize gases so that an arc could be maintained for any length of time, whereas, the 24-volt system does have sufficient potential to maintain an arc or ionize gases. This is a fundamental characteristic of the electric circuit and is quite often forgotten about when voltages greater than the critical arcing values are used. Arcing voltages are in the neighborhood of 18 to 20 volts, depending upon the materials and atmospheric pressures at the electrodes involved. The number of electrically operated devices also has been increased, and many of the electrical requirements which are vital to flight operation are therefore dependent on the continuity of electric power. Study of various means of controlling and protecting electric power systems against failures in the light of these facts has led to some interesting simple developments which are described in this paper.

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Electric Power and Protective Systems

An aircraft d-c power system like any power system consists of generators, regulators, contactors, protective devices, functional relays, and cable. The simplest system consists of generators, regulators, and reverse current cutouts. This system on multiengine planes using 28 volts definitely has indicated that improvements are desirable from the standpoint of over-all performance, reliability, safety, and full automatic features, both during normal service and under conditions where faults cause serious consequences to the electric power system and perhaps to the airplane itself.

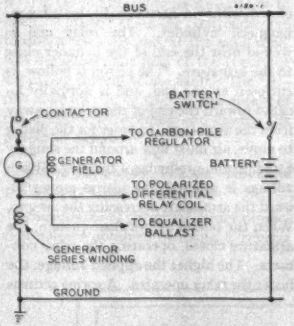

Figure 1. Diagram showing contactor at generator and no fault protection other than reversed currents and polarities

Only two protective features were incorporated in older, low capacity systems. Both were located in the cutout and controlled by the operation of a polarized relay. Polarization of the relay prevented the main contactor from connecting the generator to the bus or battery if its polarity built up incorrectly, and a series coil in the same relay caused the relay to open the main contactor in the event of excessive reverse current, preventing battery discharge.

This system and its two protective features worked reasonably well on low capacity and low voltages. On much higher capacities and higher voltages the results are not as favorable. Generator, contactor and cable faults, and overvoltage resulting from faults have caused complete loss of the electric power supply system, and have damaged batteries and other devices sensitive to power system faults as well as involving fire risks.

Several types of faults are possible and all of them have occurred at one time or another. Power systems having simple protective apparatus against these faults have been developed and are coming into use. In addition to protection against battery drain and reversed generator polarity, protection now can be provided against overvoltage from faults or other causes, grounded generator leads, grounded generators, overheated generators, and low voltage resulting from improper equalizer operation caused by wide generator speed differentials and frozen contactors. Trip-free reset may be provided for fault indications. Although these fault devices may operate infrequently, in case of trouble they are of vital importance.

Details of Protective System

Overvoltage

Overvoltage from one or more generators is caused by excessive current in the shunt field windings for the speed and load conditions under which the generator is operating. In the past, the ratio of generator capacity to the battery capacity was small in comparison to the ratio of the larger generator capacity to the battery

follow rigid rules in all respects. The general aim is to meet the requirements of the particular situations that arise, most effectively. Frequently, perhaps usually, a given end may be attained with equal effectiveness despite considerable variations in the details of accomplishment, so that personal preferences may play some part in the final solution. On the other hand, economic considerations may dictate radically different solutions to apparently similar technical problems at different places. The attempt has been made in this paper to emphasize the rather general aspects of protection; no attempt has been made to analyze technical details exhaustively. It is hoped that we have succeeded in preventing the trees from causing us to lose sight of the forest.

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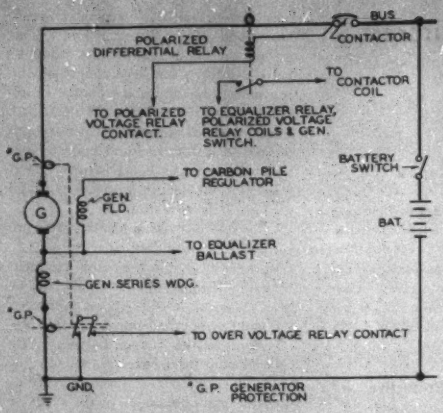


Figure 2. Diagram showing generator and generator lead fault protection

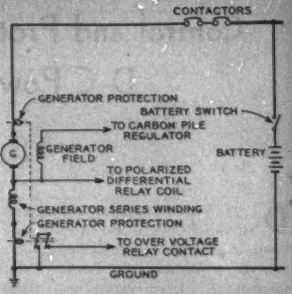


Figure 3. Diagram showing double contactors, generator, and generator lead fault protection

capacity. As a result, the battery of the smaller system could absorb excessive charging current for a much longer time without difficulty and could prevent much increase in voltage. The fault causing the trouble may be sought out and corrected at the next landing. High capacity systems do not have this advantage, and therefore overvoltage protection in larger planes and power systems is certainly desirable and is probably necessary.

Several types of faults are responsible for overvoltage conditions. Wear of carbon pile regulators has been pointed out as an offender. This condition can happen with the older models of this regulator. Design improvements reduced or eliminated this type of fault in modern regulators. However, broken leads, short-circuited terminals, short-circuited leads, or any external fault which will increase the generator field current beyond the control of the regulator will bring about overvoltage.

Relays designed to detect overvoltage operate effectively to remove from the system any generator which is producing overvoltage on the system. Operation of the relay also disconnects the generator field acting through the control devices provided for the purpose. The relay is provided with inverse timing characteristics to prevent transient overvoltage from causing nuisance operation. At 30 to 32 volts its tripping time is one to three seconds, at 60 volts its tripping time is approximately 0.025 of a second. In other words, the higher the overvoltage, the faster the action of the relay. Practically instantaneous operation at extremely high overvoltages is important to avoid damage to electronic equipment such as radio, radar, and similar devices.

After spending considerable time on the investigation of time element relays for overvoltage sensing, a relay with the following description was found which solves the problem in a very reliable manner. It consists of a magnetic piston enclosed within a hermetically sealed nonmagnetic cylinder. The relay coil is wound near the end of the cylinder close to the armature. The piston is hollow, is enclosed at one end, and is normally located toward the end of the cylinder away from the armature. In order for the piston to move, air must flow around the snuggly fitted piston, producing a time lag. When voltage is applied, the piston moves toward the armature, decreasing the air gap. When the piston moves close enough, the armature closes, operating the relay contacts. The higher the applied voltage, the faster the relay operates. A spring returns the piston to its original position when the relay is de-energized.

Multiengine airplanes with one or more generators producing overvoltage will cause the bus voltage to rise, resulting in reverse current to the generators regulated for normal voltage. This condition will cause the main contactors of these generators to trip by the action of the polarized reverse current relay. The voltage of the offending generator will rise still more, resulting in the immediate isolation of the generator from the system. The generators taken off of the bus or battery by the reverse current relay will return to normal operation through the action of the differential relay. Removing the offending generator from the system may clear the fault. The normal operating controls are reset by opening and closing the generator switch. When this is done, the generator will be automatically returned to the system, but if its voltage is still high, the overvoltage relay again

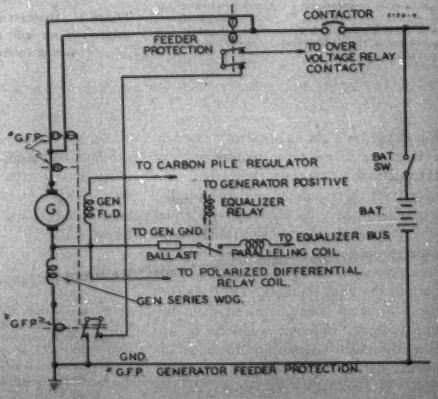


Figure 4. Diagram showing generator, generator lead fault protection plus generator feeder fault protection

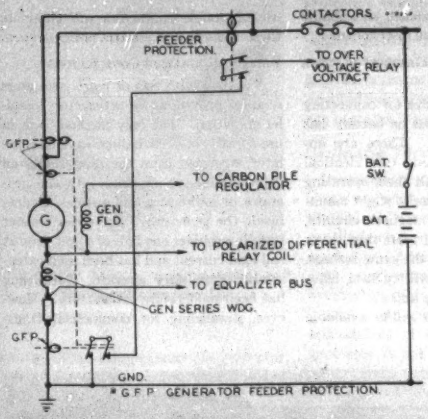


Figure 5. Diagram showing double contactors added to diagram of Figure 4

will remove it from the system. In this case, the flight engineer can decide whether or not he should reset the trip-free control again by opening and closing the generator switch. Two or three trials are considered reasonable.

Generator and Generator Lead Faults

Generator lead faults are infrequent, but probably occur more often than faults within the generator. The generator and generator lead fault protection relay will take care of both types of faults. This relay is usually mounted in the nacelle near the generator. It consists of a single contact operated by two differential series windings on the same magnetic circuit. One of the windings is in series with the positive generator lead, and the second winding is in series with the negative lead. A fault in the generator or at the generator leads unbalances the magnetic circuit of the relay, resulting in the opening of the contacts. This in turn, through the control devices provided for the purpose, isolates the generator and disconnects its field. The trip-free controls may be reset by opening and closing the generator switch. Resetting may be repeated at the judgment of the operator.

Generator Feeder Protection

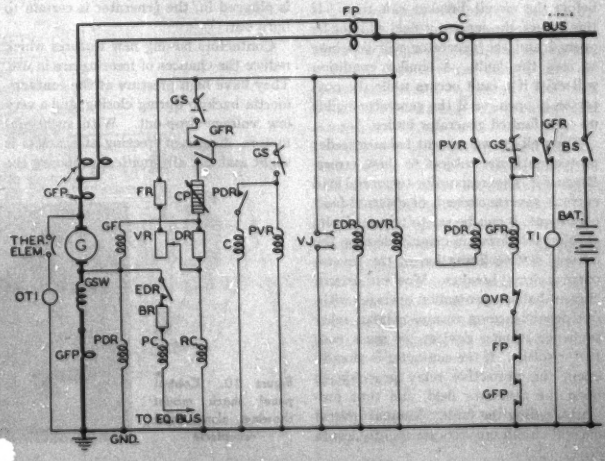
Faults can occur in cable extending from the generator in the nacelle to the bus in the fuselage. Although such faults are very infrequent in well-installed and maintained generator feeder cables, they are extremely serious when they occur. A two-lead differential method is provided for this protection. Two relays are used, each of the differential-series-coil balanced magnetic circuit type. One is located at the nacelle and the second one is located in the fuselage. Each of the two leads passes through one of the series coils of each relay. A fault of predetermined magnitude in either of the two cables will unbalance the magnetic circuit in one or both of the relays and cause its contacts to open. This will cause the control devices to isolate the fault and, at the same time, will disconnect the field of the generator supplying current to the fault. The trip-free controls can be reset at the option of the operator by opening and closing the generator switch.

Current Balance Versus Reverse Current Circuit Breaker

Some degree of generator feeder protection may be obtained by using a reverse current circuit breaker adjacent to the main contactor. When a major generator feeder fault occurs while the main contactor is closed, the circuit breaker will trip on a very heavy reverse current entering the feeder from the bus or the battery. This trip setting is normally about 50 per cent greater than the rating of the generator with a time delay, and instantaneous at currents 100 per cent above the trip setting. The high minimum trip current and the time delay feature are necessary to prevent false tripping during momentary reverse current conditions imposed by system voltage errors or by generator re-

Figure 6. Schematic diagram showing the complete control and protection of a single aircraft d-c generator

BR	Ballast resistor
BS	Battery switch
C	Contactor
CP	Carbon pile regulator
DR	Damping resistor
EDR	Equalizer disconnecting relay
FP	Feeder protection
FR	Fixed resistor
G	Generator
GF	Generator field
GFP	Generator feeder protection
GFR	Generator field relay
GS	Generator switch
GSW	Generator series winding
OTI	Overtemperature indicator
OVR	Overvoltage relay
PC	Paralleling coil
PDR	Polarized differential relay
PVR	Polarized voltage relay
RC	Regulator coil
TI	Trip indicator
VJ	Voltmeter jack
VR	Variable resistor



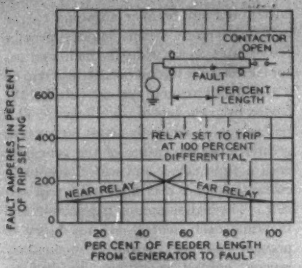


Figure 7. Curves showing fault amperes in per cent of trip setting of the protective relays for a typical generator feeder

weight than current balance and double contactors having remote reset control.

Double Break in Generator Bus Feeder

A single main contactor for connecting the generator to the bus or battery has been used extensively. There are important reasons for using two identical contactors in series with their operating coils in parallel. Because of slight manufacturing differences in magnetic circuits, springs, and mechanical parts they never may open and close at the same instant. One of them normally will operate, leaving the other as a backup unit.

The backup contactor will be available for instantaneous operation if the other unit fails to open. Frozen contacts may not cause trouble during flight, but after landing and shutdown of engines the pilot may fail to open the battery switch. In such a case the frozen single contactor will cause complete discharge of the battery. This might not damage the generator; however, if an airport power supply is plugged in, the generator is certain to burn out.

Contactors having new features which reduce the chances of freezing are in use. They have high pressure at the contacts, inertia backup during closing, and a very low voltage drop-out. With such contactors, danger of freezing of contacts is slight and, for all practical purposes, the use of double contactors will eliminate these risks to the electric power system.

Ballast Equalizer Connections

A system with two or more generators requires provisions for satisfactory parallel operation. The only methods now in use consists of coil windings in each regulator, operated from the drop across an external resistor in series with the generator or indirectly from a series winding inside the generator. The series resistor usually provides one-half of a volt drop at full load current and has been used extensively for military aircraft. Paralleling has been moderately satisfactory. However, paralleling for commercial transports should be good enough to prevent the overloading of one or more generators in flight or ground operations. Stand-by loads for 2-engine airplanes require reasonably accurate paralleling because this operating condition is likely to heat the generators more than any other phase of operation as a result of limited generator cooling air. Four-engine airplanes require paralleling to be reasonably accurate for all operating conditions because three generators must run at full output

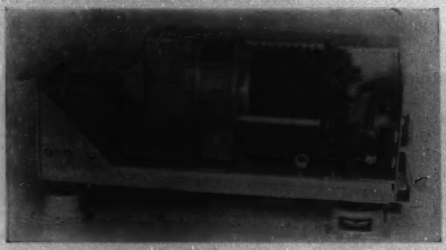


Figure 8. Control panel including regulator plugged into shock mount

Figure 9. Control panel shown in Figure 8 being removed as a single unit from the shock mount

Note separation of plug and receptacle

covery characteristics following an external load circuit fault. As a consequence, it is quite possible to have a generator feeder fault of a magnitude that will open the contactor by reverse current action before the circuit breaker can trip. If this occurs, the generator field will not be opened and the generator will continue to feed the fault. A similar condition will exist if a fault occurs while the contactor is open, or if the generator builds up on a faulted generator feeder.

The well-known current balance feeder protection is not subject to these errors. Because it is not responsive to normal load current, reverse current, or external fault conditions, it can be set to trip on faults considerably lower in magnitude than the current setting limitation of the reverse current circuit breaker. Most important, current balance protection operates without dependence on reverse current relay sequence, timing devices, or main contactor status. If the contactor is already open, the protective relay proceeds to open the generator field, and thus prevents feeding the fault. Manual reverse current circuit breakers are slightly less in

Figure 10. Control panel shock mount showing clamp and receptacle

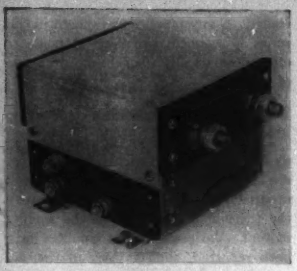


Figure 11. Nacelle type contactor and ground protection relay box

in case of the failure of any one generator.

Commercial transports are subject to delayed ground operations at many airports. The equal loading of each generator under these conditions is important. Increased equalizer voltage increases the sensitivity of the regulator to unbalanced current conditions and provides much better parallel operation. Full voltage is being taken from across the series winding of the generator and is approximately $1^1/_2$ volts.

Increased equalizer voltage also results in a lower system voltage when the speed of one or more generators is lowered to the idling value. This is an unfavorable condition, and it is corrected to some extent by a nonlinear ballast in the equalizer circuit, which limits the equalizer current under wide generator speed differences.

An equalizer disconnecting relay is also provided which opens the equalizer connection between regulators when fault protective devices operate or when the generator switch is opened. This then permits all other generators to operate at normal voltage when any one or more generators are cut out as a result of faults or shutdown. The relay is a simple voltage operated 2-position type.

Generator Thermal Indication

Overheating of the generators may be caused by overloading or insufficient ventilation at normal loads. Insufficient ventilation usually occurs under stand-by conditions. Analysis has shown that the only satisfactory device for indicating overheating of the generators is a thermal indicator sensitive to temperature and independent of current or load. The generator is not disconnected from the system when overheating is indicated, as modern insulation permits the generator to operate until the nonessential loads can be removed and the cause investigated at the next landing.

Stabilized Voltage Regulators

This type of regulator consists of a stack of carbon and graphite disks contained in a heat-radiating cylinder and a solenoid, or regulating coil, matched over a wide range to a spring which is arranged to apply varying pressure on the carbon pile in accordance with the voltage in the generator circuit. The carbon pile is connected in series with the generator field circuit so that the resistance variation through the carbon pile causes variations in the generator field current, thus obtaining constant generator voltage regardless of connected load or speed. The stability of the regulator is achieved by a damper mechanism employing both air and spring damping. Tests have demonstrated stable operation throughout the life of the regulator.

Control Apparatus Assembly And Locations

For elementary systems used on military aircraft and some commercial transports, the regulator is usually mounted in the fuselage, and the differential relay and ground resistor mounted in the engine nacelle. This is a reasonably satisfactory arrangement for this type of apparatus.

Systems provided with protective devices as described in this paper are designed with considerable flexibility as to the assembly of each unit and the mounting locations. Regulators and relays are preferably assembled on a plug-in base similar to the plug arrangements used with radio panels and racks. With this arrangement the major control units can be replaced in a few seconds. The assembly of the fault protection relays and the contactors are generally in single units and are located to the best advantage in the particular airplane being constructed.

Conclusions

Many of the simple principles used in the aircraft d-c power and protective systems are those used extensively in land power systems where continuity of service is of first degree importance.

Cable, generator, overvoltage, frozen contactor, and generator overheating faults are isolated or indicated during all operating conditions. Otherwise the system functions normally and fully automatically to connect and disconnect the generators from the battery bus as required. Satisfactory operation under conditions of humidity, sand, dust, vibration, altitude, explosive gas fumes, and acceleration normal to aircraft has been achieved by designing with these extreme conditions in mind.

Means for quick removal and replacement of the complete control panel by using standard radio plugs and receptacles provides the ultimate ease in maintenance and involves no compromises with performance. Contactors for any given power system are designed and applied so that they will interrupt successfully without undue stress any top current value that can be obtained on the system at the point where the contactor is located.

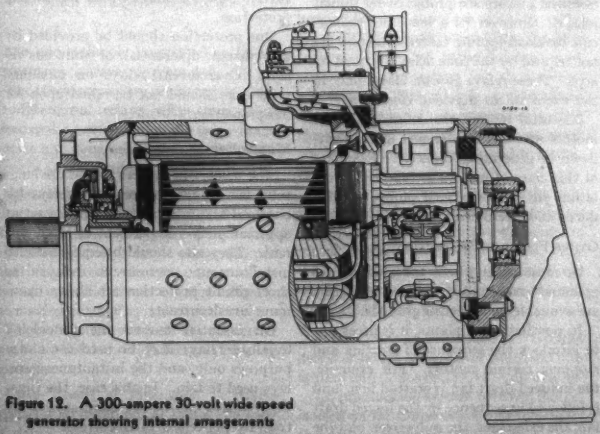


Figure 12. A 300-ampere 30-volt wide speed generator showing internal arrangements

Reference

1. An Aircraft Differential-Voltage Cutout. O. C. Walley. AIEE Transactions, volume 63, 1944, September section, pages 633–4.

Protection of Powerhouse Auxiliaries

AN AIEE COMMITTEE REPORT

THE AIEE relay subcommittee has reviewed the protection of generating stationauxiliary power motors and supply systems. The study was made to obtain information on auxiliary power systems now in use and the protective methods being applied, and to make recommendations on preferred practices.

In order to obtain basic information, a questionnaire was sent to approximately 30 engineers interested in this subject. These questionnaires covered data on the supply systems used, various forms of protection applied, and a summary of the experience obtained with these systems. Answers to the questionnaire were received from various representative companies covering both steam and hydro stations and a wide range in station sizes. The answers submitted represented the modern practice of each company. This subject also was discussed in a conference session held during the 1946 winter convention.

Summary of Information Received

Following is a brief summary of the information received on the various points covered by the questionnaire.

Supply Systems Used

In most cases, transformers are being used for auxiliary power supply. Values of 2,300 and 440 are the principal voltages used, with motors higher than approximately 100 horsepower being supplied by the higher voltage system. In most cases the systems operate ungrounded, although some companies prefer to operate grounded, either solidly or through impedance.

The protection of the auxiliary power transformers includes, in most cases, differential relays with time delay overcurrent protection for backup purposes. In many installations there are two sources of primary supply with an automatic throwover arrangement, initiated by undervoltage relays, which connects the reserve supply if the primary source is lost.

On busses supplied by auxiliary generators, the problem of bus protection is complicated by the decrement in fault current supplied by the generator. The decrement causes a rapid reduction of fault current to a point approaching normal load current, so that it is difficult to obtain bus protection with time delay overcurrent relays. In such cases differential or fault bus relays provide the most desirable method for bus protection.

Motor Protection

In the majority of cases, the 2,300-volt motors are protected by long-time-delay overload relays set at 125 to 150 per cent of full load current and instantaneous overcurrent relays on the cable leads which are set above the starting inrush current. The smaller motors are in general protected by thermal tripping elements for overload, and an instantaneous trip device for short circuits.

There is some variation in the treatment of essential and nonessential motors. In most cases, the essential and nonessential motors are protected by similar relays. However, in a few cases the circuit breakers feeding essential motors are not tripped by the time delay overload relays. These relays give an alarm only in the event of an overload condition.

Essential motors are defined as those motors whose failure results in the shutdown of generating capacity. Examples of this class of motors include the circulating pump, boiler feed pump, and induced and forced draft fans.

Other Forms of Protection

In most cases where the systems are operated ungrounded, ground detectors are available for detecting grounds.

In powdered fuel plants, it is necessary to interlock the sequence of starting and stopping certain motors. For example, the induced draft fan is started first, and is followed in sequence by the forced draft fan, the exhauster, the pulverizer, and the feeder. If any piece of equipment in this series is stopped, provision is made to stop automatically all of the motors ahead of it.

Experience and General Conclusions

The answers received indicated that as a whole the protective schemes now in use are satisfactory. The only indication of unsatisfactory performance has been with the thermal relays used on the smaller motors. Various types of troubles have been reported, such as lack of thermal capacity to withstand fault currents, and lack of sensitivity. One company uses oversize thermal elements to avoid difficulties which have been experienced with the sizes recommended by manufacturers.

In general, the importance of auxiliary power in generating stations is so fundamental that simple and rugged relaying schemes are to be desired. In almost every case the auxiliary power supply is the last element of the system which should be shut down, and therefore the relaying systems used should be as free from trouble as possible.

Recommended Preferred Practices

Supply Systems

For ungrounded systems or grounded systems where the ground fault current is limited to a few amperes, ground detector relays should be used.

For systems grounded solidly or through low impedance, residual current relays should be used on individual circuits.

Transformers supplying essential auxiliary power busses should be protected with differential relays, and time delay overcurrent relays should be used for backup protection.

Bus protection should be provided by overcurrent, differential, or fault bus relays. Overcurrent relays on auxiliary generators should not be relied upon for bus protection.

Motor Protection

The 2,300-volt motors should use long-time-delay phase overcurrent relays for overload and internal motor faults set at approximately 150 per cent of rated current. They also should be equipped with instantaneous overcurrent relays for short-circuit protection set above maximum inrush current.

On essential motors the time-delay overload relays may be used for alarm purposes only, and the instantaneous relays used to trip. In this case, the time-delay relays can be set more sensitively than 150 per cent of rated current.

Paper 46-169, recommended by the AIEE committee on protective devices for presentation at the AIEE summer convention, Detroit, Mich., June 24–28, 1946. Manuscript submitted April 19, 1946; made available for printing May 29, 1946.

This report was prepared by a working group on powerhouse auxiliaries of the relay subcommittee, AIEE committee on protective devices, consisting of E. L. Michelson (M '44, sponsor), senior engineer, Commonwealth Edison Company, Chicago, Ill.; A. H. Burkhalter (M '41), electrical engineer, design and construction department, Ebasco Services, Inc., New York, N. Y.; R. E. Cordray (M '43), in charge of relay engineering, General Electric Company, Philadelphia, Pa.; E. H. Klemmer (A '42), switchgear engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa.; W. E. Marter (A '40), assistant relay protection engineer, Duquesne Light Company, Pittsburgh, Pa.; C. L. Smith (A '28), relay engineer, electric distribution department, Rochester Gas and Electric Corporation, Rochester, N. Y.

Low voltage motors (208, 440, 550 volts) should use thermal device for overload protection, and an instantaneous trip device for short-circuit protection.

The thermal device may be built into the contactor supplying the individual motor, and one circuit breaker may provide short-circuit protection for a group of motors.

On essential motors the thermal element may be used for alarm purposes only.

Answers to Questionnaires

Following in a summarized form are the individual answers received.

COMPANY NUMBER 1

Supply System Used. This company uses transformers for supplying power to 2,300- and 440-volt busses. The transformers are operated ungrounded.

The transformers are protected by overall differential relays with time delay overcurrent protection on the low voltage output and time delay phase and instantaneous ground protection on the primary.

Motor Protection. Motors of 75 horsepower and higher use 2,300 volts. These motors have long-time-delay induction overload relays set at about 150 per cent of full load. Instantaneous relays also are used and are set to exceed slightly the maximum starting inrush current.

The 440-volt motors all are protected by circuit breakers with thermal tripping elements.

Other Forms of Protection. Static type ground detectors or lamps are used to detect grounded circuits, which are located by opening the circuits in turn.

Most essential auxiliaries are equipped with dual drive.

Both 2,300- and 440-volt busses are arranged for automatic throwover to adjacent sections in case of loss of potential, although the throwover will not function in case of a fault on the bus. Throwover is initiated when the voltage drops to about 65 per cent.

Experience. As a whole the protection has been satisfactory.

General Conclusions. It is felt that the ideal type of auxiliary power motor protection would consist of an instantaneous relay sensitive to all motor faults but insensitive to overloads, plus an overload relay with good correlation between its operating characteristic and motor temperatures.

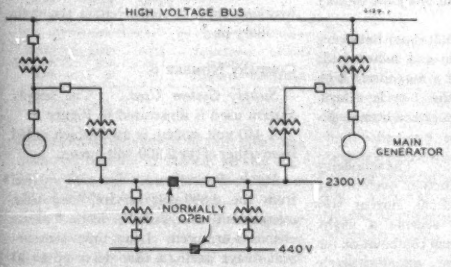


Figure 1. The supply system used by company number 2

Differential and overcurrent protection on auxiliary transformer. Differential closes bus tie when transformer breaker trips

COMPANY NUMBER 2

Supply System Used. The supply system used is illustrated in Figure 1.

Motor Protection. Motors 75 to 100 horsepower are supplied at 2,300 volts. On 2,300-volt essential motors, the protection consists of instantaneous overcurrent plunger relays for short-circuit protection. Thermal relays give visual indication only. On nonessential motors, the protection consists of 40-second overcurrent induction relays with instantaneous attachments.

On 440-volt essential motors, the protection consists of small instantaneous air circuit breakers. Thermal elements of motor contactors only light lamps. The nonessential 440-volt motors have the same protection except that the thermal elements trip the motors.

Other Forms of Protection. Ground detector relays are used on the 2,300-volt system and lamps on the 440-volt system.

An interlocking system between motors is used on the boiler auxiliaries to protect the boiler against motor failures.

Experience. The reliability of modern motors justifies a minimum of protection and maximum freedom from undesired tripping.

Relays for 2,300-volt breakers are satisfactory, but contactor elements, small air circuit breakers, and so forth, for 440-volt service are not sufficiently reliable.

Many applications require "latched-in" contactors to prevent disconnection on voltage surges.

COMPANY NUMBER 3

Supply System Used. The supply system used is illustrated in Figure 2.

Motor Protection. Motors up to 125 horsepower are connected to the 440-volt bus.

All 2,300-volt motors are protected by differential relays using instantaneous overcurrent relays set for approximately 50 per cent of full load current.

On the 440-volt system, feeders from the main bus are used to supply subbusses throughout the plant. These feeders use circuit breakers with a series trip set for 200 to 400 per cent of the rating of the breaker. These breakers protect against faults on the subbusses and heavy faults on the feeders to the 440-volt motors. Each motor is protected individually by a contactor with a thermal relay set for 30 seconds at 150 per cent load.

Other Forms of Protection. Lamps are used for ground detecting system. Grounds are removed by disconnecting portions of the system until the ground is located. The location of grounds is delayed until it is convenient to take equipment out of service.

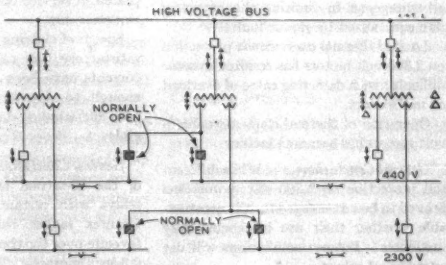


Figure 2. The supply system used by company number 3

Undervoltage relays throwover to reserve transformer

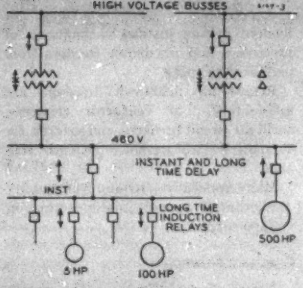


Figure 3. The supply system used by company number 5

Experience. High speed clearing of faults has resulted in very satisfactory operating conditions and has proved advantageous in limiting the extent of damage caused by motor faults.

Lack of thermal overcurrent protection on 2,300-volt motors has resulted in some difficulty with detecting cases of overload on mill motors.

Operation of thermal elements on 440-volt motors has been satisfactory.

General Conclusions. While differential protection on 2,300-volt motors has proved to be advantageous, it is questionable whether their use is economically justifiable. Future installations will use overcurrent relays.

Company Number 4

Supply System Used. The supply to auxiliary power is from transformers 13.8/2.3 kv, delta-Y connected. The 2.3-kv neutral is grounded solidly. Smaller motors are supplied from a 575-volt system, which in some cases is grounded and in other cases ungrounded. The transformers are protected by differential and induction type overcurrent relays.

Motor Protection. Motors up to 100 horsepower are supplied from the 575-volt system.

Motors are protected by a 40-second induction-type relay with instantaneous attachment. The time delay element is set at approximately half way between the ordinates of the motor full load temperature curve and the curve representing motor thermal limitations. The instantaneous trip is set just over "locked rotor" current. In some instances, thermal relays are used which are set in the same manner as for the induction relays.

No distinction is made between methods employed for protection of essential and nonessential motors except that the instantaneous auxiliary overcurrent relays set at approximately 115 per cent of the rated current are applied to pulverizer motors. These relays stop the coal feeder motors upon overload of the pulverizer until the pulverizer motor current drops back to normal.

Other Forms of Protection. Very elaborate interlock systems are used between induced and forced draft fans, pulverizers, boiler feed water pumps, and so forth.

Ground lamps are used for ground protection. No grounds have developed to date.

Experience. Performances of protective and control schemes have been excellent. All thermal relays of a certain make have had to be dismantled and reassembled in our laboratory before being placed in service because of poor factory workmanship.

Speeds of clearing faults have been very satisfactory; all cable and motor fault currents have been of a magnitude high enough to operate the 1-cycle relays. Iron and winding damage has been negligible.

General Conclusions. The simplicity of the 40-second induction overcurrent relays with instantaneous current trip features makes this scheme a slight favorite over the thermal combination for 2.3-kv motors. The manufacturer's standard protection on 575-volt cubicle switchgear has been found satisfactory.

Company Number 5

Supply System Used. The supply system used is illustrated in Figure 3.

Motor Protection. All motors are supplied at 460 volts (5 to 500 horsepower).

The 40-second induction overcurrent relays are used on almost all auxiliary motors. Current settings are from 125 to 150 per cent of motor rating. Time settings are generally about one second minimum time.

Instantaneous trips are used on all group breakers to clear any short circuit of sufficient magnitude to affect the operation of other motors.

Other Forms of Protection. Mill motors and exhauster fans are interlocked. Coal conveyer systems are all interlocked.

A set of ground indicating lamps with series resistors is installed on each auxiliary bus. Ground is established, for test, by a push button. This is a routine test performed by the operator on each shift. A ground is a rare occurrence on these 440-volt busses, but as soon as one does occur it is usually possible to cut in duplicate equipment and clear the trouble.

Experience. Our experience with thermal relays has not been satisfactory. The testing and maintenance cost has been extremely high. We have found that the long time induction overcurrent relay, though slightly more expensive initially, is far more reliable, maintains its calibration, and is easy to test. Quite a few of these motors are equipped with thermoguard protection. We have not used these devices for tripping, but have considered the possibility of doing so.

General Conclusions. Differential protection is not justified on 440-volt auxiliary motors because winding failures are rare.

Instantaneous tripping should be provided for every group or feeder circuit breaker which is connected to the main auxiliary bus.

Company Number 6

Supply System Used. The supply system used is illustrated in Figure 4.

A 440-volt system is used which is fed from either of the 2,300-volt busses.

Motor Protection. On motors fed from the 2,300-volt service, long time overcurrent relays with instantaneous elements are used. Long time overcurrent relays having a time delay up to 40 seconds are used and can be set for 110 to 125 per cent of full load current and with sufficient time delay to ride over the starting inrush. The instantaneous elements are set above starting inrush and furnish protection for faults on motor leads and circuit.

The main 440-volt motors are equipped with individual circuit breakers with thermomagnetic overload protection. This

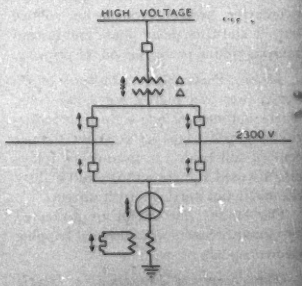


Figure 4. The supply system used by company number 6

provides both overload and short-circuit protection for these motors. Time delay undervoltage type *CV* relays are used on the 2,300-volt motors.

Other Forms of Protection. Automatic transfer of busses from the transformer to the generator source is provided to transfer load in case of voltage failure. The transfer scheme is interlocked to prevent paralleling of busses or to transfer after an overload relay operation.

The 440-volt busses have automatic transfer between transformers connected to the two 2,300-volt bus sections and have interlocks similar to the 2,300-volt busses.

Experience. The protective schemes used have given very satisfactory service and no load curtailment or shut down has occurred because of station service failures. The equipment described is new and few failures have occurred.

Table I

Motor Voltage	Max Hp	Min Hp	Protected by
2,300	1,000	300	Individual circuit breakers
550	250	50	Individual circuit breakers
550	50	1/3	Magnetic contactors

General Conclusions. The long time overcurrent relays with instantaneous attachments seem to offer satisfactory protection for the 2,300-volt motors since they can be set low enough to prevent roasting of insulation on overload, and the instantaneous elements provide quick clearing for severe faults.

Company Number 7

Supply System Used. The auxiliary power is supplied by transformers at 2,300 and 550 volts. The supply busses are operated ungrounded.

Protection consists of differential relays on the transformer banks and time delay induction overcurrent relays on all supply transformer circuit breakers.

Motor Protection. Motors are supplied as indicated in Table I.

Motors controlled by individual circuit breakers have

1. Instantaneous overcurrent relays set slightly above motor starting current.

(a). On 2,300-volt motors these are plunger type relays actuated from current transformers.

(b). On 550-volt motors these are built into breaker housing.

2. Time delay overcurrent relays set to pick up at 125 per cent of motor rated current and with sufficient time delay so as not to trip during motor starting.

(a). On 2,300-volt motors these are induction type operated from current transformers.

(b). On 550-volt motors these are thermal devices built into the breaker.

3. Thermal devices built into the motor structure which open a contact when the motor temperature exceeds a safe value and sound an alarm.

Motors controlled by magnetic contactors have

1. Air circuit breaker for instantaneous short-circuit protection.

2. Thermal overload built into the magnetic contactor.

All motors controlled by circuit breakers are treated as the foregoing.

1. Essential motors controlled by magnetic switches have thermal overload two sizes above that recommended for the size of motor involved.

2. Nonessential motors controlled by magnetic switches have thermal overload one size above that recommended for the size of motor involved.

Other Forms of Protection. An alarm is provided on each ungrounded bus to inform operator when a ground occurs. It consists of double-Y potential transformers with the neutral grounded on the high voltage side and overvoltage plunger type instantaneous relays connected from phase-to-neutral of the secondary winding. When a ground occurs the two relays on the ungrounded phases pick up and sound an alarm.

Experience. Fortunately the occurrences of short circuits on the auxiliary power system have been few and far between. In cases where short circuits have occurred, the instantaneous overcurrent relays in general have operated to clear the circuit with very little resulting damage to the equipment. Also, for *overload* conditions few cases have been experienced, for in general the size of motors chosen have had ample capacity to take care of the maximum mechanical load demanded. In the few cases where overload conditions occurred, the time delay induction overcurrent relays have done a good job without serious damage to the motors. In case of the thermal devices the experience has not been quite as good but not serious enough to change the scheme of protection.

General Conclusions. The use of ungrounded auxiliary power system employing a ground fault detecting system and eliminating the ground immediately after it occurs reduces to a minimum the number of short circuits that occur on the system. Further, the use of instantaneous overcurrent relays do a very satisfactory job when such short circuits do occur. In the use of instantaneous overcurrent relays, care should be taken that they are set at their minimum pickup value (that is just a little above the starting current) and not the general value sometimes recommended of ten times the circuit breaker rating. Also, the employment of induction overcurrent relays set at 125 per cent of motor rated current appears to be more reliable than other forms of overload protection.

Company Number 8

Supply System Used. The supply system used is illustrated in Figure 5.

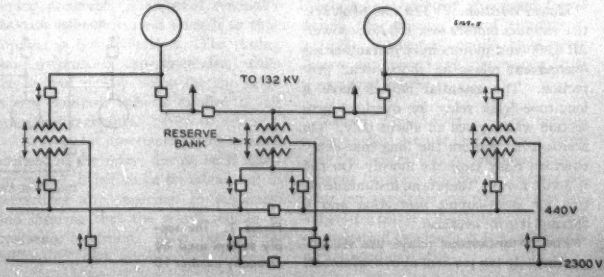
Motor Protection. The 2,300-volt system supplies motors from 175 to 600 horsepower, the 440-volt system 1/2 to 200 horsepower.

Motor protection consists of the following:

1. On all 2.3-kv equipment—one overcurrent long-time relay with instantaneous attachments and two instantaneous overcurrent relays, two current transformers with an overcurrent relay connected in the residual circuit of the two current transformers.

2. On all 440-volt equipment—air circuit breakers (deion) with time delay and instantaneous relays.

Figure 5. The supply system used by company number 8



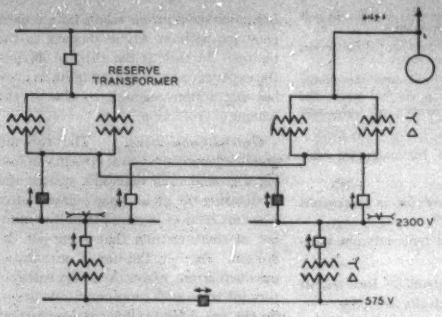


Figure 6. The supply system used by company number 9

Undervoltage relays throwover to reserve transformers

3. Undervoltage type *CV* relays on 440-volt bus trips pulverizer mills.

4. Most 440-volt motors have individual air circuit breakers with thermal trips.

No preference is given between essential and nonessential circuits on relaying procedure.

Automatic throwover of both 2.3-kv and 440-volt busses is provided.

Other Forms of Protection. Interlocks are used on pulverizers and coal scales, also on forced draft and induced draft fans.

Ground detectors are located on both 2.3-kv and 440-volt busses.

Experience. Present relays are very satisfactory. However, those originally installed (two overcurrent standard relays with instantaneous attachments) could not be set to co-ordinate properly with motor starting. Faults have been cleared very quickly and no extensive damage has resulted to motors or cables.

General Conclusions. The afore-mentioned scheme (one overcurrent and two instantaneous overcurrent relays) seems to us to be a very workable and efficient scheme.

Company Number 9

Supply System Used. The supply system used is illustrated in Figure 6.

Motor Protection. The 2,300-volt system supplies motors over 100 horsepower. All 2,300-volt motors have instantaneous overcurrent relays for short-circuit protection. The essential motors have a long-time-delay relay for overload protection which gives an alarm only. On nonessential motors the long-time-delay overload relay trips the motor. On the 575-volt motors, there is an instantaneous trip for short-circuit protection and a thermal trip for overload.

The instantaneous relays are set approximately ten per cent above maximum motor inrush current, that is, ten per cent above asymmetrical peak value occurring in the first half cycle.

Other Forms of Protection. Boiler fan motors and mill motors are interlocked for sequence starting and stopping.

Ground relays on 2,300-volt and 575-volt busses operate an annunciator. Grounds are removed by disconnecting one motor feeder at a time until the ground is located.

Experience. Provision has been made to trip almost all of the motors immediately in case of a short circuit in the feeder or the motor. In faults of this nature the amount of damage is limited by the quick tripping. In a recent case of motor failure it was possible to remove the faulted coils from the circuit by using jumpers and keep the motor in service.

Some difficulty is experienced in co-ordinating the instantaneous direct acting trips of the 575-volt circuit breakers. Where these breakers are cascaded a short circuit usually trips all of them in the cascade with loss of unfaulted motors or feeders. Dashpot devices have not proved satisfactory for this purpose. A simple device, such as an adjustable escapement, on the instantaneous trips for a few cycles timing would be of material benefit in solving the problem.

General Conclusions. In general, the protective scheme adapted is considered reasonably economical and simple and has performed satisfactorily with the exception of the cascading referred to in the foregoing paragraph.

Company Number 10 (Hydroeletric)

Supply System Used. The supply system used is illustrated in Figure 7.

Motor Protection. All motors are supplied at 550 volts. The motors are supplied through individual "Non-fuz" breakers. Between each of the breakers and the individual motors, there are magnetic switch starters with a suitable thermal relay for overload protection.

Other Forms of Protection. The station service is not grounded and there is no means of detecting and removing grounds.

Experience. No difficulty has been experienced with any part of the station service.

Company Number 11 (Hydroeletric)

Supply System Used. All auxiliary power motors are supplied at 550 volts. The supply is from transformers that are fed from house generators. These transformers are protected by overcurrent relays. The auxiliary power supply system is grounded solidly.

Motor Protection. All auxiliary motor circuits are protected by overcurrent inverse time relays, plus overcurrent instantaneous elements at a higher setting.

Other Forms of Protection. No other forms of protection are used.

Experience. Experience in operating for 13 years with this protection system has not shown any defects in the method. However, no essential auxiliary motors or circuits have developed a fault thus far. The crane motor-generator set and two sump pumps are the only equipment to develop any trouble, and the trouble was not extensive. A coil or two short-circuited

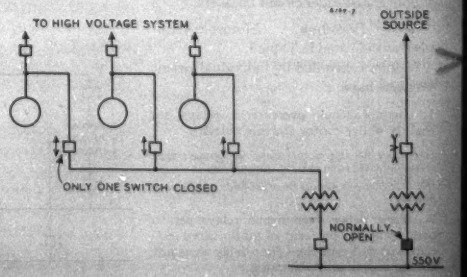


Figure 7. The supply system used by company number 10

Six Years' Experience With Factory-Built Unit-Type Substations

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THE Iowa-Illinois Gas and Electric Company installed its first unit-type substations late in 1939. At the present time, there are installed in the various operating districts of the company nine unit-type substations. We are outlining the reasons for the choice of this type of substation and the distribution system into which the substations are being fitted. This paper will cover our operating experience with six of this type of substation located in the quad-city area of Davenport, Iowa; Rock Island, Moline, and East Moline, Ill. The reasons given for the selection of this type of substation, the design of the distribution system served by the substation, and operating experience so far encountered are typical also of the other districts in which the additional three substations are located.

The quad-city area comprising the cities outlined above occupies two states, Iowa and Illinois. The division between states and cities is made by the Mississippi River. Davenport, Iowa, and its suburban towns, occupying the north bank of the Mississippi River and located in the State of Iowa, comprise a total population of approximately 90,000. The cities of Rock Island, Moline, and East Moline, Ill., with their attendant suburbs located on the south bank of the Mississippi River, comprise a total population of approximately 114,000.

Because of the advantages offered by the Mississippi River, the bulk of industry is concentrated along the river banks. The cities of course started their growth on the banks of the river and have expanded outward. Greatest load concentrations are along both banks of the river with the residential load being located in an approximate semicircular area around the outside of the industrial area. Original substations are located close to the river in the heavy industrial and commercial areas.

Polyphase alternating current was introduced into the quad-city area in 1888, six years after the first electric service was installed. This early a-c system was 2-phase, and, as a result, all growth on the quad-city system for many years was 2-phase. This 2-phase service was utilized in two ways.

1. The 2-phase 4,800-volt primary circuits were used to supply industrial customers.
2. The 2-phase 2,400-volt circuits were used to supply lighting customers.

The 2,400-volt system was utilized throughout much of the residential area as single phase primaries. The distribution system remained single phase 2,400-volt and 2-phase 4,800-volt until late in 1939. In the meantime, a backbone transmission and subtransmission system of 69-kv and 13.8-kv 3-phase circuits was built which served the complete quad-city area.

The later load growth has tended to be away from the river to keep pace with the expanding residential areas and some smaller outlying industrial areas. Because of growth of the communities, the load center of residential load kept shifting out away from the river and the original manually attended substation locations. This change in load center was followed by lengthening of the distribution lines until the long lines introduced poor regulation despite the use of induction feeder voltage regulators. Interruptions of service on these long feeders involved a large number of customers. As the areas grew, a number of small outlying commercial areas developed in which only single phase service was available. This offered many disadvantages to the merchants located in these areas as much of the equipment which they purchased normally came equipped with 3-phase motors.

The requests for polyphase service were each of relatively small electrical demand and scattered over fairly large areas. As a result, it was uneconomical to construct long polyphase feeders from the existing substation locations to serve the widely diversified loads of small magnitudes. The many requests for polyphase service received from the outlying areas required that consideration be given to the establishment of polyphase primaries in these localities. The location of the existing substations and number of circuits already leaving those stations made it difficult to get out additional circuits without going considerable distances underground, thereby raising the cost of each of the outgoing circuits which would be required.

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in the sump pumps which caused tripping by the overload protection during running, and clearing took place quickly enough to prevent any spreading of the fault. The crane motor-generator set became defective because of broken coil leads caused by insufficient bracing to withstand line start operation. The overload relays occasionally would trip out during the starting period for some time before the condition developed in enough bars to prevent satisfactory operation. No burning or spreading of the damage resulted, and it was difficult to locate the flaws which had occurred in the winding.

It should be remembered that in line start operation of motors the overload relay moves toward closing its contacts every time the motor is started, and the timing preferably is adjusted originally by trial to be just great enough so that tripping is not completed. The timing thus determined experimentally, while the desired pickup value for the relay is not changed, then is applied to all other similar circuits.

The frequent movement of the moving element of the relay, during each starting period, is felt to be an advantage in preventing any tendency to stickiness and insuring that the relays remain in operating condition. After the original calibration and conditioning following installation, recalibration checks are required infrequently since operating conditions can be proved roughly by simply observing the amount of contact travel during the starting up of equipment. Actually, subsequent checks have never shown an appreciable divergence from the original values.

General Conclusions. The conclusions reached are not new and only agree with the general idea of providing instantaneous tripping devices to operate on fault currents plus low-pickup-value inverse-time relays for satisfactory clearing of prolonged overloads or low current internal winding faults.

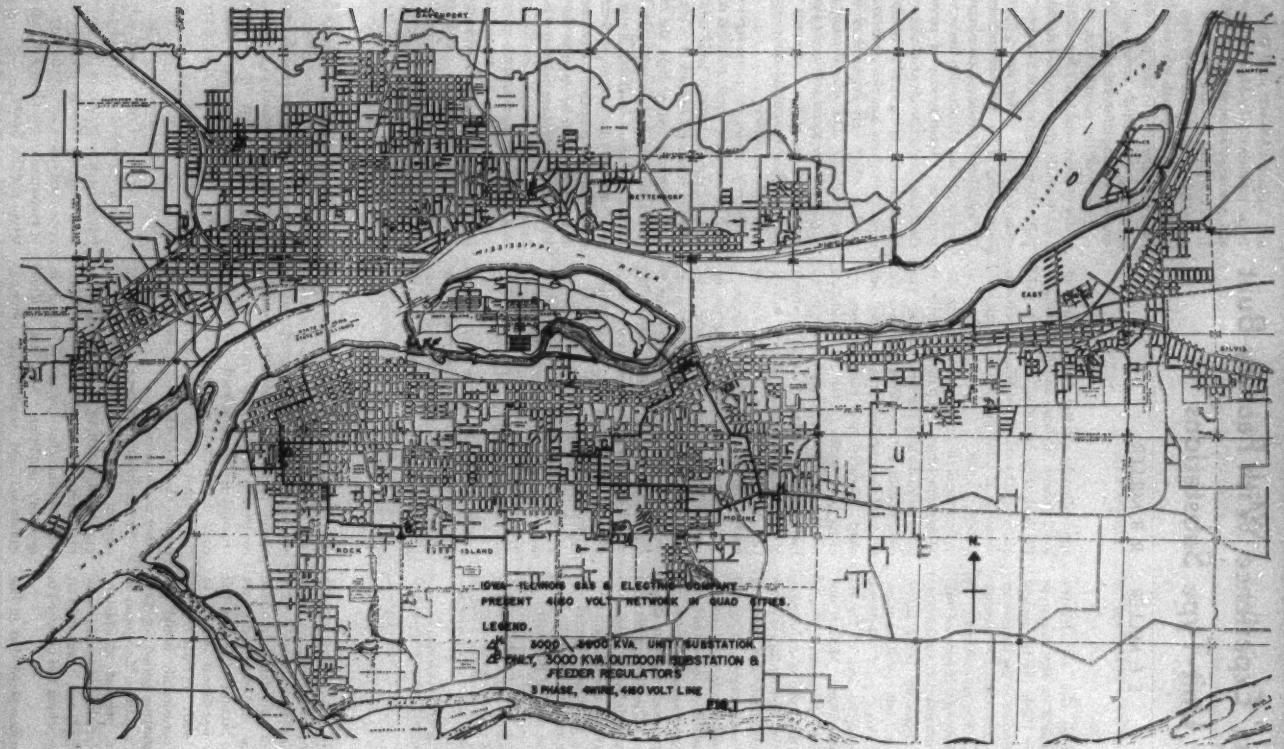


Figure 1. Present 4,160-volt 3-phase 4-wire network in quad cities

Δ^H—3,000/3,900-kva unit substation
Δ^B—only 3,000-kva outdoor substation and feeder regulators

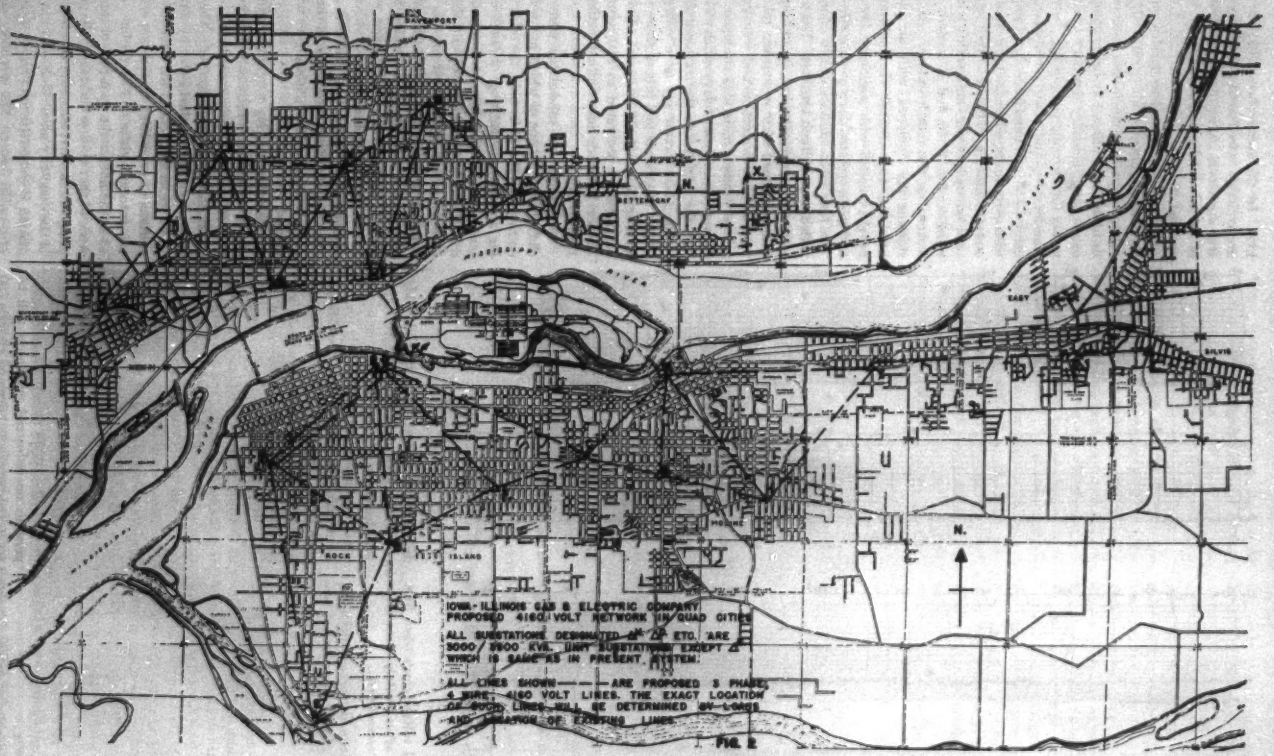

IOWA-ILLINOIS GAS & ELECTRIC COMPANY
PROPOSED 4160/ VOLT NETWORK IN QUAD CITIES
ALL SUBSTATIONS DESIGNATED Δ^H, Δ^P ETC. ARE
3000/3900 KVA. UNIT SUBSTATIONS EXCEPT Δ^A
WHICH IS SAME AS IN PRESENT SYSTEM.
ALL LINES SHOWN - - - - ARE PROPOSED 3 PHASE,
4 WIRE, 4160 VOLT LINES. THE EXACT LOCATION
OF SUCH LINES WILL BE DETERMINED BY LOADS
AND LOCATION OF EXISTING LINES.
N.
FIG. 2

Figure 2. Proposed 4,160-volt 3-phase 4-wire network in quad cities

All substations designated Δ^H, Δ^P, and so forth, are 3,000/3,900-kva unit substations, except Δ^A which is the same as in the present system

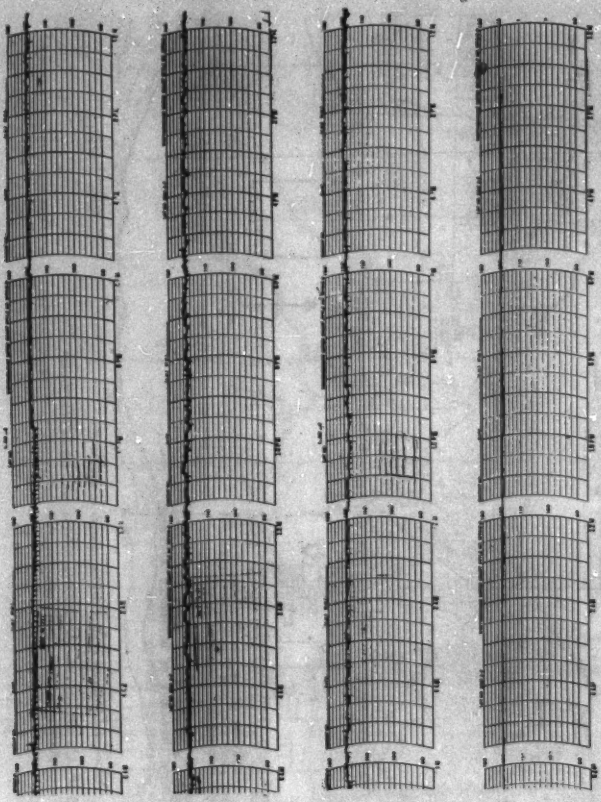


Figure 3. Typical voltage charts taken from secondary circuit approximately three spans from transformer

Transformers are located approximately one mile from the unit substation at center of 4-kv tie

Increased loads on existing substations required that additional larger capacity supply lines be constructed to those substations. The increased line capacity supplied through the larger number of step-down transformers raised the short-circuit duty on all existing station equipment. As a result much of the present station equipment became inadequate in interrupting capacity and thermal capacity. In addition, the fact that much of the existing station equipment was 2-phase also made it obsolete.

In 1939 it was decided to modernize the distribution system. After careful study of various types of distribution systems, it was decided that 4-kv primary networks would be instituted independently for the communities on each side of the Mississippi River. Because of the width of the river, it was deemed not advisable to join the 4-kv networks on opposite sides of the river. Involved in the study of the type of distribution system to be constructed was the matter of the type of substation to be utilized with the distribution system. After considerable study it was decided to use factory-built unit-type outdoor substations, these substations to be supplied from the 13-kv system and to be 3-phase 4-kv on the output side.

The majority of these substations will serve the residential areas, outlying commercial and small industrial areas. In general, no industrial customers will be served whose original demand exceeds 300 kva. In the areas where 13-kv circuits are available as well as 4-kv circuits, industrial customers having demands in excess of 100 kva will be supplied from the 13-kv system.

The type of substation decided on has the following description: 3,000/3,900 kva, equipped with transformer secondary breaker, four 3-phase 4-kv feeder compartments, and necessary auxiliary compartments for metering equipment, operating transformers, and other essential equipment. The individual feeders are equipped with overcurrent relays having instantaneous attachments. Three shot reclosers are used on each feeder, automatic reclosing being set for 15, 30, and 45 seconds with lockout on the fourth outage. All substations are equipped with air circuit breakers, the original two substations being equipped with stationary breakers and group operated disconnecting switches. The four later substations are equipped with drawout circuit breakers. The transformer secondary breaker, in addition to being equipped with overcurrent relaying for bus fault protection and transformer failure protection, is also equipped with network and phasing relays which will connect the 4-kv bus to the transformer and to the 13-kv circuit any time voltage of proper magnitude and proper phase quality is applied to the 13-kv circuit. Individual breakers are rated as 600 amperes, 7.5 kv with an interrupting rating of 150,000 kva.

Originally, two substations were purchased in 1939, one of which had a cable entrance on the 13-kv side, the other having an overhead entrance through cover bushings with lightning arresters mounted directly ont he transformer cover. Experience with bushing flashover on this substation within the first month after it was placed in service caused a decision to be reached that all future substations would have 13-kv cable entrance. No switching equipment is provided on the 13-kv side except a pole-top switch on one of the last poles before the 13-kv circuit goes underground.

The accompanying diagram, Figure 1, shows substation locations and indicates the portions of the primary network which so far have been tied together. The unit substations are supplied either by a radial 13-kv feeder from one of the attended substations or generating stations, or from a tap onto an existing 13-kv tie line. The 13-kv tie lines make up a part of the network of that voltage embracing the generating stations and all attended substations of the quad-city area. Only one unit substation is connected onto either a tie line or a radial feeder. The secondary side of

each substation is tied into the 4-kv primary network. Each substation has at least two of its feeders, and ultimately will have all of its feeders, tied into other substations in the network. Radial load in the area through which each 4-kv tie line passes is balanced on the three phases of the tie line. This includes both the residential as well as the small commercial and small industrial load which already have been mentioned.

Actual construction of the primary network was delayed by the war. In addition to the substations now in service, one other substation has been on order since May 1945, and we contemplate the installation of six additional unit-type substations in the next 5-year period. The accompanying diagram, Figure 2, shows the ultimate network as planned with the future substations shown dotted. Substations are located in the small commercial areas adjoining residential districts. Where possible under zoning ordinances, substations will be located in the residential area. All 4-kv feeders are taken out underground, the actual underground distance being determined by the varying conditions at each substation site. The 4-kv tie circuits between unit substations are constructed as follows: outgoing riser cables with a 300,000-circular-mil single conductor and either paper-insulated lead-covered, or rubber-insulated with a Neoprene jacket. Where paper-insulated lead-covered cables are used and the neutral conductor is pulled in the same duct with the phase conductors, insulated wire is used. Generally, this has been a copper conductor of 4/0 size with a single layer of paper insulation and a lead sheath, although we have used some rubber-insulated braid-covered wire when wartime restrictions prohibited the use of lead on conductors insulated for less than 2,500 volts. The overhead conductors consist of three 4/0 phase conductors and a 1/0 neutral. The neutral wire is marked by means of white porcelain insulators and the phase conductors are always placed in sequence with the neutral as a marker. Construction, in general, is made to conform with the surrounding neighborhood. In some cases underground feeders have been run as far as two city blocks before rising to meet the overhead system.

Spacing of unit-type substations is determined by load in areas to be served, length of tie lines to other unit substations, planned future additions to the network, and by regulation based on the fact that bus regulation is used. Because the bus is regulated instead of the individual feeders, we have determined that no ties between stations will be over $2^1/_2$ miles long. In general, substations are spaced from 2 to $2^1/_4$ miles apart, and voltage regulation has been very satisfactory as shown by the accompanying charts, Figure 3.

Maintenance on the substations has been very slight. A regular weekly visit is made to each substation at which time all equipment is inspected, dust and dirt are removed by means of an electric vacuum cleaner and blower combination, records are made of kilowatt-hours and demand, and readings of the various operation counters are noted. A weekly inspection report is made out on each substation covering the various data taken, and space is provided for notes covering unusual maintenance, record of relay operations as indicated by targets and other matters of interest. A single spare circuit breaker is on hand which can be used to replace any of the existing breakers which require maintenance. For the circuits which are supplied from both ends, such as ties between substations, it is a simple matter to change circuit breakers without having interruption of service. For circuits which are strictly radial feeders, a time is chosen to interrupt service while the breaker is being changed which will cause the least inconvenience to the customer involved. In the six years of operation with these substations, only two minor cases of repairs in circuit breakers have been necessary.

We believe that the primary network

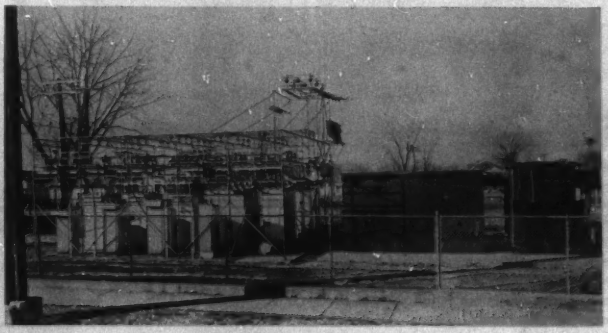


Figure 4. A 3,000/3,900-kva unit substation located in the same lot with a 1,500-kva substation of the open conventional design

The 1,500-kva open type substation was later removed and the material used at other locations

Figure 5. Close-up view of one of the standard 3,000/3,900-kva unit substations

and the use of unit substations have a number of advantages over the radial type of system. The location of the substation close to the load center keeps losses to a low value and provides for better regulation. The bulk of the energy is supplied at the subtransmission voltage which insures better system regulation and a more economical source of energy. The 3-phase low voltage lines provide better regulation with lower losses. The use of 3-phase tie circuits makes it easy to supply polyphase service to small commercial areas and outlying industrial locations. Spare transformer capacity is not required as in the conventional radial system. Voltage charts taken on the substation busses and on the customers' premises indicate that for the most part a smaller variation in voltage is maintained than where induction voltage regulators are used on radial-type feeder circuits. This of course accounts for better operation of appliances, particularly fluorescent lighting units, greater customer satisfaction, and increased revenue. Continuity of service through the use of primary network is excellent. The absence of induction feeder voltage regulators lowers maintenance costs as well as first costs, and operating and maintenance costs have been much lower than they are for the identical radial system.

We have found that a standard design of unit substation can be utilized to work out in the quad-city area as well as in the smaller outlying districts which incorporate a 3,000/3,900-kva transformer with one transformer secondary breaker and four feeder breakers. This size of transformer was chosen on the basis of cost per kilovolt-ampere and load density which we encounter in the area served, coupled with a reasonable distance between substations. Air blast equipment is supplied on the transformers when they are purchased and they provide an economical reserve capacity which is required occasionally in the event of other substations in the network being out of service at times of peak load.

In addition to the relays and other control equipment already mentioned as being standard with the substation used, we use a recording wattmeter, a recording varmeter, three recording ammeters, and a recording voltmeter of the strip chart variety to give us a continuous record of those quantities. These instruments are all connected into the leads of the transformer secondary so that the quantities measured pertain to the substation as a whole. A voltmeter switch is used to get a record of individual phase to ground voltages. A 1-week record per phase to ground quantity is normally obtained. No indicating or recording instruments are provided on the individual feeders. Test blocks are provided, however, on the control panel for each feeder to permit easy installation of portable recording instruments where checks need to be made for magnitude and division of load on each circuit.

Provisions for future expansion are excellent. It is possible to add additional unit substations at any time at the points of maximum load growth and it is also possible to move a substation in its entirety if load shifts dictate, thereby salvaging the bulk of the investment in a substation installation. System planning through the use of a-c network calculators has permitted the selection of the most economical size of unit-type substation, the most economical number of circuits, proper loading of the various substations, proper control of regulation for the complete distribution system through the use of bus regulated substations, and adequate provision for future growth.

Frequent use is made of the a-c network calculator to keep ahead of network growth, to anticipate the requirements for additional substations, and to check the operation of the existing network. In this way we are able to check substation locations with respect to load growth and to anticipate well in advance the locations where future substations must be installed, and to plan network changes and additions to meet system requirements in the best way.

Figure 6. View of substation with air circuit breaker in drawn out position

Figure 7. View of one of the units set in edge of residential area, showing landscaping used

Systems Development of Military Communications

THOMAS R. PUTNAM
MEMBER AIEE

Synopsis: It is the purpose of this paper to set forth the broad phases of the problems involved in establishing a telephone and telegraph landline system in a military theater of operations, the manner in which these problems were met, and the results obtained in the North African Theater of Operations. The aspects reviewed are those involving the unification of the theater-wide wire facilities into a single system including maximum integration of civil plant and military installations, with centralized supervisory control of the available resources.

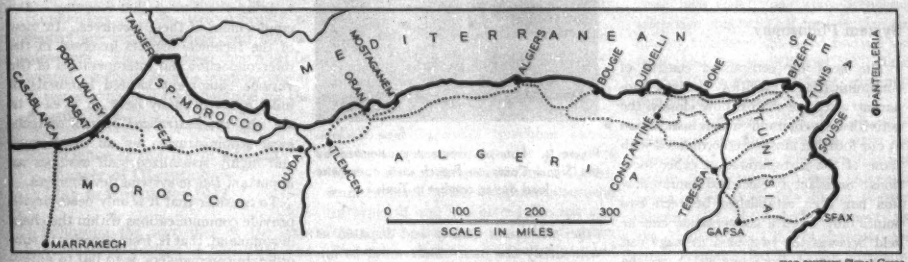
IN the North African Theater of Operations the landline communications system handled thousands of telephone calls and thousands of telegraph messages daily, over many hundreds of miles of telephone and telegraph channels involving distances, in some cases, greater than the distance between New York and Chicago. To provide an adequate system of communications for the Armed Forces in the field requires the fullest exploitation of the available communications resources, both personnel and equipment, if satisfactory service is to be furnished with maximum economy in the employment of these resources. The system communications problem involves a landline network and radio and submarine cable circuits operated as links in the landline network, both telephone and telegraph. To accomplish the mission of providing these communications, it is essential that an appreciation of the system philosophy be acquired by all concerned with the planning, engineering, installation, and operation of these facilities.

It might be worth while to consider for the moment the basic nature of the communication service required by the Armed Forces in areas in which extensive land and land-based air operations are carried out. In smaller units, perhaps up to and including division level in the ground forces, the primary purpose of communications is for fire control. That is to say, communications are required between commands posts, forward observers, observation posts, gun and infantry positions, and armored elements, to bring fire power to bear on the enemy when and where needed. Communications for this purpose have been largely on a point to point basis, especially in fast moving situations. However, as a given situation tends to become stabilized, a larger share of the traffic over the circuits is for administrative and supply service purposes, the number of users increases, the number of points required to be reached by telephone or telegraph increases, and switching facilities and system operation become a necessity.

Above division or perhaps corps level, the physical plant required begins to take on the appearance of a system network rather than a series of point to point routes. Many main routes are required, oftentimes passing through the areas of control of several commanders. For example, the requirements of the air forces for long haul circuits for intercept, tactical, and strategic air operations are governed by the deployment of the air forces. The location of the air installations depends not only upon the current tactical situation, but broad geographical and other considerations as well. Other governing factors in the location of main routes in the rear areas are the locations of ports of supply and other large administrative and supply centers. For these reasons the communications required to serve these areas must be considered as a system with many of the same problems we find in commercial operations.

In this connection, it seems desirable to look into the experience of commercial communications organizations and certain inherent features of their operations. The commercial operation of a landline communication service and its associated radio and submarine cable links has been described as a natural monopoly for the reason that the greater the number of facilities integrated into a single system, the greater is the value of the service to the users. It is on this basis that the need for a strong centralized control of the over-all operation is primarily recognized. This same necessity and reason exists in the development of a system of military communications. In addition, only by means of an integrated communication organization can the required flexibility in allocation of resources be attained to provide facilities when and where needed.

A major difference between the opera-



map courtesy Signal Corps

Figure 1. Map showing main landline routes in French North Africa

Approximate route distances, miles:	
Algiers–Oran	340
Algiers–Casablanca	890
Algiers–Constantine	320
Algiers–Bizerte	580
Casablanca–Marrakech	150
Casablanca–Bizerte	1,470

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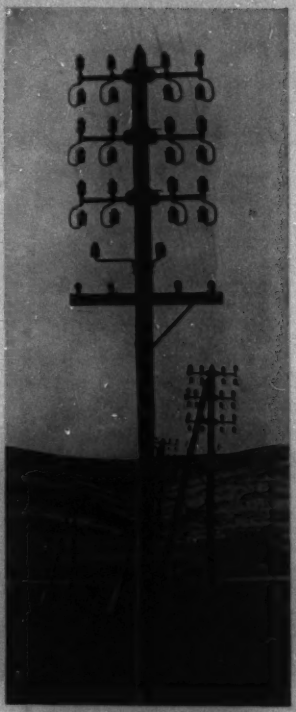
tion of a military communication system in the field and commercial operations, however, is the method by which the requirements are limited with respect to the available supply of facilities. In general, the normal peacetime demands on a commercial service are kept in reasonable balance with the available supply of facilities by virtue of the cost of the service to the users, which in turn is related to the investment. This means of regulating the needs of military users, however, is not applicable in areas of military operations, which is another reason for centralizing appropriate technical control of communications at the highest level of military authority in the area served by the system.

Another major difference between military and commercial systems is the fact that the development of a commercial system is usually characterized by an orderly change of requirements, with time factors permitting the installation of an economical, well-designed plant. However, the pressure of limited time in the development of a military network in a theater of operations seldom permits the thorough co-ordination of all concerned to the extent desired.

System Philosophy

The need for centralized control of communications facilities becomes apparent when we realize how closely the activities of a communications installation at one location must be co-ordinated with those of the installations at other locations. Satisfactory electrical communication has been established between two points only when a conversation can be held between the two, or a message can be transmitted from one point to the other with such quality and dispatch as will satisfy the user. Delays due to unwarranted interruptions or lack of cooperation between those responsible for operations at various points in the system are evidence of unsatisfactory service.



Signal Corps photo

Figure 2. Four-pin crossarm constructed by the Signal Corps on French civil open wire lead during combat in Tunisia

It is not sufficient that all individuals and organizations place and splice field wire or lead-covered cable; construct and maintain pole lines; place open wire; install and line up carrier terminal and repeater equipment; install, maintain, and operate telephone and telegraph switchboards and radio installations in accordance with the same manuals of instructions. These activities must be carried out by organizations and personnel in several commands at the same time. The only way this possibly can be done without delay and confusion is by adopting basic principles of military signal communication organization which will permit the designation of a single agency in advance to be responsible for laying down the ground rules under which this work is to be accomplished. Furthermore, these ground rules must be binding on all commands whose communications are an integral part of the system as a whole.

It may be accepted as axiomatic that rarely will sufficient resources be available in a theater of war to satisfy the communications requests of all users. It therefore becomes incumbent upon those responsible for providing this service to exercise the utmost in judgment and skill to bring about maximum economy in the employment of these resources. In view of the technical aspects involved in the interconnection and interoperation of the various equipment located hundreds of miles apart in many cases, it is easy to see why the centralized control of technical administration by an experienced and highly specialized staff assumes an important role in systems development.

To consider that it is only necessary to provide communications within the chain of command, that is, from superior to subordinate commanders, is to fail to appre-

Figure 3. Signal Corps personnel operating a French civil switchboard with French interpreters at Oran

Signal Corps photo

Figure 4. Signal Corps personnel operating Creed teleprinters (British) at Allied Force Headquarters in Algiers

Signal Corps photo

ciate the realities of modern operations. Were this the case, the provision of communications would be relatively simple. The problem is to provide a single network for use of all commanders and staffs of all elements of the armed forces occupying a given area, and it is under these conditions that complexity is added to the system. A further complication is added and in no small degree, in the provision of communications for joint operations involving the land, sea, and air forces of not only our own, but allied nations as well, utilizing the native resources of each, including civil systems.

In those overseas theaters in which organizational difficulties were encountered in systems development of communications during World War II, these difficulties stemmed from a basic deficiency in signal communications doctrine as promulgated by the War Department. Briefly stated, this doctrine sets forth the principle that every commander controls the system of communication required for his command. This principle of control by the several subordinate commanders must not be confused with the concept that the technical control of the single system of physical plant must be exercised by the common superior of these commanders. These two concepts of control are complementary and not inconsistent. For this reason they must be treated coequally in any pronouncement of signal communication doctrine for the Armed Forces.

Experience in the North African Theater of Operations—May to November 1943

Following the surrender of the Axis land forces in Tunisia in May 1943, the landline communication system of the Allies extended from Marrakech and Casablanca to Tunis and Bizerte in French North Africa, covering a maximum distance of about 1,600 miles. Communications operations expanded considerably following the cessation of ground combat operations for the mounting and support of two major amphibious operations, Sicily in July, and Italy (Salerno) in September 1943. To give some idea of the magnitude of the facilities required, following is a tabulation of the long haul channel mileages operated during the fall of 1943:

1943	Channel Miles	
	Telephone	Telegraph
September	36,500	29,300
November	38,300	34,400

The outside plant making up this network consisted of existing French civil (Services des Postes des Telegraphes et des Telephones) open wire leads and buried cable, American 10-pin and 8-pin open wire leads, American spiral four cable, and buried cable placed by both the American and British forces. Many of the French civil open wire leads in Tunisia had to be rehabilitated following combat operations in that area.

The equipment used to derive the long haul channels included French civil systems and varieties of American and British equipment available at the time. The French installations consisted chiefly of 1- and 3-channel telephone carrier systems operated over the open wire leads between Rabat and Oran. American telephone carrier equipment consisted of types *H* and *C* Western Electric systems, providing one and three carrier frequency channels, respectively; and Signal Corps type CF-1 which provides one voice frequency telephone channel and three carrier frequency telephone channels. British equipment consisted of the so-called "one plus one" (one voice frequency telephone channel plus one carrier-frequency telephone channel) and "one plus four" (one voice frequency telephone channel plus four carrier frequency telephone channels) tactical systems, and British SOS and SOT (three carrier frequency telephone channels) commercial systems.

Both American and British voice frequency telegraph systems were employed for long haul telegraph (teletypewriter and teleprinter) use. American types consisted of type 40-C-1 Western Electric (12 channels) equipment and the Signal Corps CF-2 (4 channels) tactical system. British voice frequency telegraph systems used, were the "speech plus simplex," "speech plus duplex," and "6 channel duplex" tactical systems. The "speech plus duplex" (S plus Dx) and "speech plus simplex" (S plus Sx) systems are designed to derive carrier telegraph from a portion of the frequency band used by a telephone channel while retaining the use of the channel for speech transmission. In the S plus Dx system the band from about 1,500 to 2,000 cycles is eliminated from the speech transmission circuit and used for telegraph purposes. The carrier midband frequencies employed are 1,680 cycles for one direction of transmission and 1,860 cycles for the other direction. Carrier is transmitted for marking and interrupted for spacing. The S plus Sx system provides service in both directions on a circuit but in only one direction at a time (American half

Signal Corps photo

Figure 6. Main distributing frame of the Freedom Exchange installed by the Signal Corps at Algiers

Signal Corps photo

Figure 5. Switchboard installers of the Signal Corps at work on an 8-position Western Electric 11 type switchboard at Algiers

Duplex). A choice of carrier frequencies is available in this latter system depending on which of the three types of the equipment is used. Numbers 1 and 2 are arranged to use frequencies of 300, 900 or 2,300 cycles per second. The number 3 equipment uses frequencies of 300, 1,740, or 2,300 cycles per second.

Multichannel very high frequency radio equipment as developed and later used in other overseas military areas as links in landline systems was not available in the North African Theater; and a discussion of the point to point radio operations is outside the scope of this paper. In the fall of 1943 a limited amount of broadcasting was done over transmitters in the vicinity of Tunis from studios in Algiers, using landline program supply channels. Although these channels were not high quality, they did serve the purpose. Musical programs of the Special Services and foreign language news were broadcast for short periods at night. Also, on several occasions news broadcasts picked up at points in Tunisia were carried over landlines to Algiers where they were transmitted by radio to this country for broadcast.

The Mediterranean area has a rather well-developed civil network of submarine cables which proved to be extremely useful to the Allied Forces. A considerable volume of intratheater telegraph traffic was carried over these circuits particularly after the islands in the Mediterranean between French North Africa and Italy were occupied. In respect to security considerations, submarine cable circuits are unique in that they are acceptable for transmission of military telegraph traffic in clear text, including messages classified as secret, providing the water areas through which the cables pass are in complete control of friendly forces. In view of the shortage of automatic cryptographic equipment, the advantage of this was that arrangements could be made if the condition just mentioned were fulfilled, for the clearing of large volumes of telegraph traffic without the time-consuming burdens of manual cryptography.

To develop a theater-wide system of communications involving complex operating features as just described, it soon was found that staff responsibility without technical administrative authority over the operating personnel of the various subordinate commands was entirely unsatisfactory. The solution to this problem in French North Africa was to activate liaison offices called long lines district offices, in Oran, Algiers, Constantine, and Bizerte to be under the direct control of the wire division of the signal section, Allied Force Headquarters. This action was taken in September 1943. Signal Corps officers and enlisted men were assigned to these offices who were entirely familiar with the "big picture" of the system and who were technically competent to analyze maintenance and operations results.

Figure 7. Signal Corps personnel operating an 8-position Stromberg-Carlson 18 type switchboard at Constantine

Signal Corps photo

Telephone Operations

In September 1943 it was found necessary to restrict the number of telephones having access to the long distance service. Long distance calls were permitted from about 50 per cent of all the telephones connected to military switchboards. The effect of this policy was an immediate improvement in the service, and by October between 85 and 90 per cent of all long distance calls which were placed were completed on the first attempt on a non-hang-up basis.

The principal headquarters telephone switchboards completed an average of approximately 60,000 calls per day in the month of November 1943. Conservatively estimating the number of calls handled in addition on smaller switchboards for which records were not available, the total number of telephone connections was probably in excess of 150,000 per day.

Table I

Location and Switchboard Designation	November 1943 Type of Board*	Number of Positions	Number of Calls Per Day
Algiers			
Algiers long distance	WE 11	6	5,570
Freedom (local)	WE 11	10	20,457
Bizerte			
Bizerte (combination local and long distance)	TC-1	5	5,557
Eagle (local Eastern Base Section)	TC-1	3	5,003
Casablanca			
Beacon (combination Atlantic Base Section)	WE 550	3	6,589
Constantine			
Constantine (combination)	SC 18	8	5,829
Oran			
Merit long distance	TC-1	6	3,375
Merit local (Mediterranean Base Section)	WE 11	8	16,086
		Total	68,766

* WE—Western Electric; TC-1—Signal Corps nomenclature; SC—Stromberg-Carlson.

Table II. Landline Telegraph (Teletype) Traffic Data* for Certain of the Major Signal Centers in French North Africa—June and November 1943

Month	Allied Force Headquarters	Atlantic Base Section	Mediterranean Base Section	Eastern Base Section
June	95,638	27,379	42 938	18,650
November	114,087	9,886	52,187	27,926

* Daily average—incoming and outgoing words (excluding press).

The record of calls passed on the principal boards as recorded from actual peg counts is shown in Table I.

Telegraph Operations

The first voice frequency telegraph system in French North Africa using American equipment was installed in March 1943. Signal Corps CF-2 four channel equipment was installed in Algiers and Oran and operated over a French civil underground cable circuit. Prior to that time all voice frequency telegraph channels were provided by means of British equipment of the type mentioned earlier. Also, in the same month of March, sufficient teletype switchboards (Signal Corps BD-100) had become available to establish a common user telegraph printer network. Switchboards of this network were installed at Oran (Mediterranean base section), Algiers (Allied Force Headquarters, Air Force, port, and other service organizations), and at Constantine (Eastern Base Section); and at later dates the system was extended to include Casablanca, Tunis, and Bizerte.

The telegraph traffic load of several of the larger headquarters in French North Africa for June and November 1943 is shown in Table II.

Technical Administration

The development of a network of communications into an efficient system requires a scheme of technical administration which will enable each member of the communication team to know not only what his own duties and responsibilities are to carry out a given function, but also what other members of the team at distant points should be doing. For routine matters this is best accomplished through the medium of a set of uniform practices or instructions issued under a competent order to all concerned. A few of the activities which must be covered in this way are service order and trouble reporting routines, and long distance circuit order and facility record practices. These instructions must take into account all the conditions affecting the operation of the communication system, such as the communication procedures of all the military and civil agencies and commands involved in the operation, and the numerous types of equipment and organizations available to the military forces and civil communication administration. Instructions of this kind are applicable only to the communication system of a particular area of operations, and for this reason they must be prepared in the field by the agency responsible for the operation of the system. In the North African Theater of Operations these instructions were issued as "Operating and Maintenance Instructions," by the wire division of the signal section, Allied Force Headquarters.

By the fall of 1943, plant operations showed considerable improvement over earlier results. Contributing largely to this improvement were the extensive inside and outside plant preventive maintenance programs which were put into effect during the summer, the introduction of universal patching facilities, and the substantial on-the-job training acquired by the maintenance personnel. In addition, of major importance was the improved operation of the plant on a system basis following the activation of the afore-mentioned long lines district offices. For example, during the two months immediately following the establishment of these offices, telephone carrier troubles of one hour or more duration decreased 40 per cent, and similar telegraph carrier troubles decreased 50 per cent during the same period. These improvements in carrier maintenance operations provide strong evidence as to the soundness of the system doctrine applied to military communications operation. The over-all experience in the operation of the landline system in French North Africa leads inevitably to the conclusion that a single chain of command must exist from the very top down through all signal communication organizations involved in providing a communications system for military operations in a theater of war.

Frequency Compensated A-C Ammeters and Voltmeters

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Synopsis: The increased use of a-c instruments over a frequency range of 25 to 3,000 cycles for aircraft and industrial applications has imposed new requirements on instrument design. It is recognized that the standard type of a-c ammeters and voltmeters normally calibrated for use at a given frequency are subject to errors in indication when used at other frequencies. This paper describes the manner in which one line of a-c ammeters and voltmeters can be compensated to have minimum errors resulting from changes in frequency over a range of 25 to 3,000 cycles. Errors found in the uncompensated and compensated types of instruments with changes in frequency are shown, and a practical means of determining the amount of compensation and its application to ammeters and voltmeters is presented.

FOR many years the conventional types of a-c ammeters and voltmeters have been designed for operation over a small range of power frequencies from 25 to 125 cycles per second and have been used primarily on 25-, 50-, and 60-cycle circuits. In recent years, however, the operating frequency range has been extended[1] and instruments have been designed with improved magnetic materials to operate accurately over a range of 15 to 12,000 cycles. Some of the more common frequencies encountered in the extended range have been 180 cycles for portable machine tools and high speed motors, 400 and 800 cycles for aircraft, 960 to 3,000 cycles for electric furnace applications, and from 8,000 to 12,000 cycles for industrial heat treatment use.

The more general method of instrument adjustment has been to calibrate at 60 cycles for use at 25 to 125 cycles and at the specified operating frequency for higher ranges. This procedure in the past has proved satisfactory and, generally speaking, variations up to 20 per cent of the calibrated frequencies have not produced objectionable errors. A rapidly increasing demand, however, has developed recently for instruments to be used over much wider frequency ranges. For example, in aircraft there have been applications for instruments for use on not only 400 but 800, 1,200, 1,600, and 2,100 cycles. The problem of equipping these airplanes and maintaining replacement supplies would be simplified greatly if an instrument calibrated at one frequency

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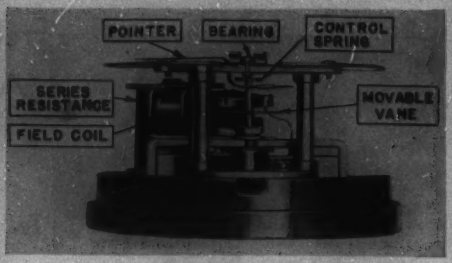

Figure 1 (left). Representative panel type a-c instruments for industrial and aircraft applications

Figure 2 (above). Instrument assembly showing mechanism and internal construction

also would perform accurately over the complete range. Similarly, in many modern industrial and electronic applications the operating frequency may vary over ranges much in excess of 20 per cent of the calibrating frequency. These conditions have created a need for instruments which are compensated over a wide frequency range. A method of compensation and the results obtained are described in this paper.

Errors in Uncompensated Voltmeters and Ammeters

The moving iron instrument of the attraction type used for many a-c ammeters and voltmeters is shown in Figure 1 in typical sizes. Briefly, the mechanism of this instrument consists of a vane of high permeability material moving within a fixed coil and mounted on a nonmagnetic shaft which carries the indicating pointer and is supported in suitable bearings. When current flows in the fixed coil, a magnetic field is set up which tends to pull the magnetic vane into the coil. The rate with which the vane is pulled into the coil is controlled by a flux distributor, and the movement is opposed by the torque of a control spring attached to the shaft. The internal construction of this type of instrument is shown in Figure 2.

This mechanism is used in ammeters by allowing the current to be measured to flow through a field coil. For voltage measurements, the mechanism is connected across the line and in series with a fixed resistance, to permit a current proportional to voltage to flow through the field coil. The electrical circuit of a standard uncompensated voltmeter is shown in Figure 3.

The voltmeter is subject to frequency errors which are caused by changes in the inductive reactance of the field coil and of the series resistor, and in the effective a-c resistance of the coil. The impedance of this typical design at 60 and at 3,000 cycles is shown vectorially in the two diagrams in Figure 4. While the change in inductive reactance is directly proportional to the change in frequency, the relation of the change in effective resistance with frequency is more complex. It has been shown previously[2] that the eddy current losses in magnetic circuits vary as a nonlinear function of the frequency, and have the same effect as a resistance which shunts the field coil and decreases the current through it. The combined effect of these two factors is to increase the circuit impedance and decrease the indication for a given voltage as the frequency increases.

An example of errors in an uncompensated voltmeter of this type is shown by the calibration check of a typical 150-volt voltmeter in Table I. The instrument was calibrated at 60 cycles and checked over a frequency range of 60 to 3,000 cycles. The differences in readings at 60 cycles and other designated frequencies are expressed in per cent of full scale voltage. This rating of voltmeter has a series resistance of 14,000 ohms which limits the current through the field coil to 10 milliamperes.

The frequency error in ammeters of the moving iron type is caused only by the change in eddy current losses and is not affected by inductive reactance changes which merely cause a change in the voltage drop across the coil, but not in the current through it. As a result, the overall error is considerably less than that found in voltmeters. For example, the error of a 5-ampere ammeter, similar in general design to the 150-volt voltmeter described and adjusted on 60 cycles, does not exceed minus 3 per cent at full scale indication on 3,000 cycles.

Method of Frequency Compensation for Voltmeters

A study of frequency errors shown in Table I, indicates that voltmeters should be compensated for frequency changes when calibrated at one frequency and used over a wide range of different frequencies. The ideal, from the users standpoint, would provide compensation to hold the magnitude of the total effective impedance constant even though the values of the resistive and reactive components change as the frequency varies. A study of prior methods[3,4] has shown that compensation can be obtained by shunting all of the series resistance with a capacitor of required value if the resistance of the series resistor is relatively large as compared with that of the field coil.

This method is very undesirable for use in quantity production, as the value of capacitance must be held within much closer limits than the standard plus or minus 20 per cent tolerance in the micro-

Table I. Uncompensated Instrument Errors Over Frequency Range

Expressed in Per Cent of Full Scale Value

Standard Voltage	Cycles				
	60	400	1,200	2,000	3,000
60	0	−0.8	−2.3	− 4.9	− 8.9
90	0	−1.1	−3.6	− 7.6	−11.2
120	0	−1.1	−4.7	− 9.3	−14.8
150	0	−1.8	−5.1	−12.0	−22.0

farad values of capacitors which are available in quantity, and in the dimensions required. Furthermore, such capacitors will be subject to peak voltages which are more than can safely be impressed on them. For example, a capacitor which shunts 14,000 ohms of a 15,000-ohm instrument circuit would be subjected to a peak voltage of 198 volts at full scale indication, and to even much higher values for intermittent overloads to which instruments may be subjected.

These difficulties, however, can be overcome largely by shunting only a portion of the series resistor and varying the resistance value of this portion to match the actual capacitance of a given capacitor. Since the value of this resistance is determined during the test procedure, and the resistor spool then is wound to the required resistance, it is not necessary to maintain a large inventory of these resistor spools, and commercial tolerance capacitors can be used without difficulty in quantity production. In addition, the voltages likely to occur across them are reduced to safe values.

With this method, the amount of compensation and, therefore, the magnitude of the remaining error in a given voltmeter, depends upon the per cent of the series resistor which is shunted and the value of capacitance used. The effect of different per cents of series resistor shunted, and the magnitude of errors over a 60- to 2,500-cycle frequency range, is indicated in Figure 5. As shown, shunting 58 per cent of the resistor with a 0.004-microfarad capacitor reduces the errors to a maximum of 1/4 per cent over the frequency range. If, however, this compensation is used on 3,000 cycles, a 1 per cent error will occur. On the other hand, errors over the range extended to 3,000 cycles can be made negligible by shunting 75 per cent of the resistor with 0.003 microfarad.

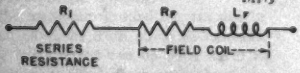

Figure 3. Schematic diagram for uncompensated moving iron type voltmeter

R_F—Field coil resistance
L_F—Field coil inductance
R_1—Series resistance

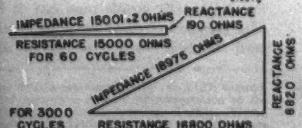

Figure 4. Vector diagrams showing how internal impedance varies with frequency

Application of Method to Actual Voltmeters

It is important to note that the preceding values are for an individual voltmeter and will differ slightly with each instrument as a result of the tolerances which must be allowed in the components. The different values of series resistance which were shunted by a fixed value of capacitance in order to fully compensate a group of six instruments are shown in Table II.

Table II. Variations in Resistance Shunted by Fixed Capacitance

Capacitor Rating, μf	Resistance Shunted, Ohms	Resistance Unshunted, Ohms	Per Cent Shunted
0.003	10,300	3,700	73.6
0.003	10,385	3,615	74.1
0.003	10,390	3,610	74.1
0.003	10,520	3,480	75.3
0.003	10,715	3,285	76.6
0.003	10,880	3,120	77.7

This method of shunting a portion of the series resistance approaches closely the ideal compensation by maintaining nearly constant the magnitude of the total effective impedance over wide frequency ranges. This is shown in Table III for which the equivalent resistance R_e and the equivalent reactance X_e have been computed from measured values for each component by using the following equations:

$$R_E = R_F + R_1 + \frac{R_2}{R_2^2\omega^2C^2+1} \text{ ohms}$$

$$X_E = j\omega\left(L_F - \frac{R_2^2C}{R_2^2\omega^2C^2+1}\right) \text{ ohms}$$

where R_F, L_F, R_1, R_2, and C refer to the components shown in Figure 6. The vector relationship of these values at 3,000 cycles is shown in Figure 7.

The data in Table III were taken for the full scale point only, and other points on the scale will vary slightly as a result of changes in the demagnetizing effects in the magnetic circuit resulting from the movement of the vane in and out of the field coil. The magnitude of such changes is shown in Table IV and is considered satisfactory for the applications previously mentioned. It is significant to note that the scale distribution changes with frequency and that such changes are more pronounced at the higher frequencies.

The application of this method of frequency compensation to large quantity production of voltmeters is entirely practical. The voltmeter first is adjusted at 60 cycles with the fixed coil in series with the resistance required for full scale. The frequency then is changed to 3,000 cycles, which increases the instrument impedance and decreases the pointer indication. A commercially available capacitor of approximately the right value then is connected across a sufficient amount of series resistance to bring the pointer again to the full scale point. This adjusting technique can be adapted easily to simplified test procedure by using standard resistors of different values which can be quickly connected to the instrument circuit by a selector switch.

Compensation of Lower Range Voltmeters

The discussion thus far has been restricted to voltmeters rated 0–150 volts. Lower range voltmeters can be compensated in the same manner if certain new problems are solved. In order to assure adequate factors of merit and temperature compensation, it is necessary to maintain a given number of ampere-turns for the field coil, and a definite ratio of the resistance of the copper in the

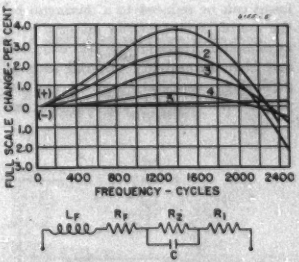

Figure 5. Degree of compensation for different percentages of series resistor shunted by specified value of capacitance

Decade Box For Resistors R_2 and R_1

Curve	Ohms R_F	Ohms R_2	Ohms R_1	μf C
1	1,000	3,645	10,650	0.025
2	1,000	3,300	10,700	0.025
3	1,000	4,200	9,800	0.015
4	1,000	5,750	8,250	0.008
5	1,000	8,100	5,900	0.004

field coil to that of the series resistor which is wound with negligible temperature coefficient material. These and other factors result in the series resistance decreasing more rapidly than the field coil impedance, as the full scale voltage rating is reduced. As a result, voltmeters in ranges below 75 volts do not have sufficient series resistance to be shunted for correct frequency compensation. It is necessary, therefore, either to make some sacrifice in performance or to design special high frequency instruments for such ratings to obtain effective compensation.

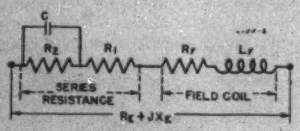

Figure 6. Schematic diagram for compensated moving iron type voltmeter

R_f—Field coil resistance
L_f—Field coil inductance
R_1—Unshunted series resistance
R_2—Shunted series resistance
C—Capacitor

Compensated Ammeters

It has been pointed out previously that the frequency errors in the ammeters are relatively small as compared with those found in voltmeters and principally are a result of eddy current losses. These losses can be reduced to a minimum by the use of high resistivity material such as phosphor-bronze for the field coil form and high permeability material such as permalloy, mumetal, and nicaloi in proper combination in the magnetic circuit. As a result, errors in ammeters are reduced to negligible values over the frequency range of 60 to 3,000 cycles.

Table III. Variation of Total Effective Impedance With Frequency

Frequency, Cycles Per Sec	R_E, Ohms	X_E, Ohms	Z_E, Ohms	Per Cent Variation of Z_E From Value at 60 Cycles*
60	15,030	70	15,030	0
400	15,090	493	15,090	+0.40
1,200	15,030	1,280	15,080	+0.33
2,000	14,820	2,130	14,970	−0.40
3,000	14,300	4,290	14,960	−0.50

* With the sign reversed these values are equal to the per cent error at full scale caused by frequency variation.

Table IV. Typical Scale Errors Over Frequency Range in Per Cent of Full Scale

Standard Voltage	Cycles 60	400	1,200	2,000	3,000
150	0	0	0	0	0
120	0	+0.1	+0.2	+0.6	+1.4
90	0	−0.3	−0.8	−0.1	+1.1
60	0	+0.4	−1.1	−1.1	−0.7

Conclusions

A practical technique of frequency compensation has been developed which can be applied easily to standard a-c instruments. The compensation has been accomplished first, by the use of improved magnetic materials in the ammeter and voltmeter, and secondly, by the addition of a commercially standard capacitor to the voltmeter.

By the application of these simple improvements in existing designs it is possible to use instruments normally adjusted for accuracy to within plus or minus two per cent of full scale value for one frequency, over a wide range of 25 to 3,000 cycles without incurring additional errors in excess of two per cent.

It is hoped that this work will encourage the use of frequency compensated a-c instruments to replace those now calibrated for a standardized frequency of either 60, 400, or 800 cycles as well as those calibrated for other specific frequencies. This will insure more accurate measurement of current and voltage over a wide range of frequencies.

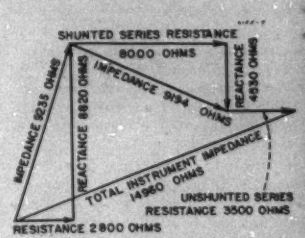

Figure 7. Vector diagram showing total instrument effective impedance at 3,000 cycles

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Sensitive Ground Relay Protection for Complex Distribution Circuits

LLOYD F. HUNT
FELLOW AIEE

Synopsis: Protection engineers always have desired to obtain a system of ground fault protection that will discriminate and actually trip out only the ground faulted circuit of a complex distribution network. This has been a difficult chore because the magnitude of the ground current often varies so greatly as to be out of the range of the normal protective relay settings. A system is proposed here that not only has proper discrimination, but also operates on very low amounts of ground current with the maximum ground current held to such a low value that practically no harm or damage is done by the ground fault. This development was encouraged by the necessity of joint use of poles by lines of communication circuits and distribution circuits. This method comprises the installation of a small bank of grounding transformers at each of the stations where the lines originate or terminate. With these small ground banks the maximum ground fault current is very small. Adequate relays and systems are used to isolate only the faulted sections of line. The installation of one 11-kv and one 16.5-kv loop will be described. These two systems have had several years of successful operation.

Conclusions

THIS type of sensitive ground relay protection will discriminate on ground currents in the order of one per cent of the current transformer ratings, that is, with a 200–5 current transformer on the circuit, a fault of two amperes ground current will cause proper tripping.

The maximum ground current can be arranged to be from 40 to 60 amperes. This low current can do little harm as compared to the damage caused by a current of several thousand amperes that may occur in the solid grounded neutral systems. It has been found by years of operating experience that the damage done on ground faults with this type of protection is negligible.

Tests have been made with tree grounds and it has been shown that conductor contacts on green trees do not pass sufficient current to trip the lines out from this cause. Years of operating experience have confirmed this fact.

The operation of this relay scheme can be made very fast, thus eliminating ground faults rapidly. Since the control of the ground relays can be used to control the phase relays, phase-to-phase short circuits also can be cleared rapidly.

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Introduction

Continuity of service to the customers of electric power utilities always has been one of the main problems of the protection engineer. Complex and interconnected high voltage circuits have been common for a long time. The protection of these circuits has been satisfactory and is improving continually. The lower voltage circuits have the same advantage of giving better continued service when interconnected. This has been done for some time but there has been no reliable way of isolating ground-faulted feeders correctly when the range of ground current has been so great. Therefore development of such a system was begun. Various standard types of relays were applied to many systems and no reliable discrimination could be obtained.

Then two further requirements became apparent:

1. If successful operation is to be obtained in joint pole use, the distribution line upon contacting the telephone circuit should be isolated rapidly and with as small amount of current as necessary to properly clear the distribution circuit. It is important to both the telephone utility and the power utility to make these fault damages a minimum as they both serve the same customers and continuity of both services is important.

2. The damage to property and the hazard caused by fallen live wires makes it necessary to isolate and de-energize them as rapidly as possible and with as small amount of ground current as necessary.

It can be seen that the same relay system can accomplish each type of ground fault isolation. During many years, ground tests were conducted with many types of relay systems and many improved ones were developed, but most of them were not adequate to service a complex distribution system. The system described here was finally suggested and tried. Although rather complicated for distribution circuits, it has proved successful with years of experience. Several improvements have been made to facilitate operation. The system herein described is now in service on some of the

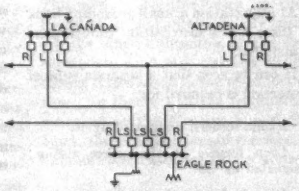
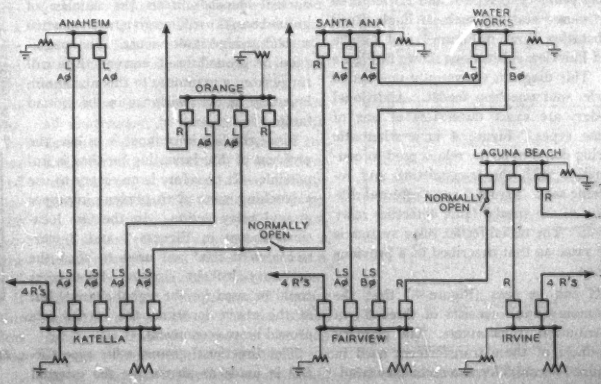


Figure 1. Eagle Rock substation 16-kv loop system

Figure 2 (below). Katella and Fairview substations 11-kv loop system



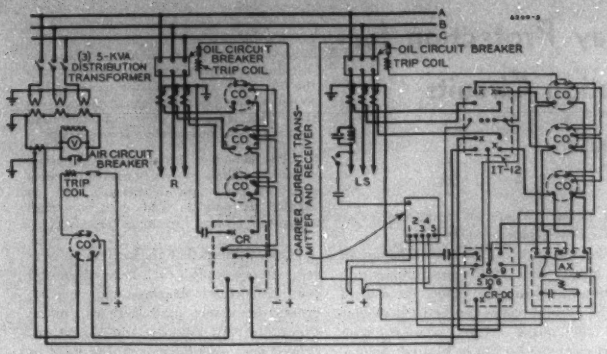


Figure 3. Source station relay system

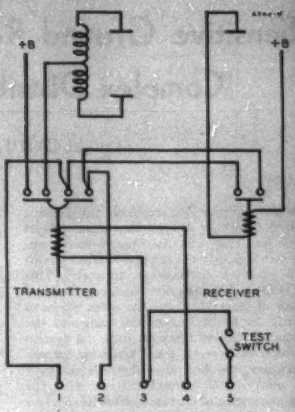


Figure 4. Carrier set relay system

distribution circuits of the Southern California Edison Company Ltd.

Complex Distribution Systems

The sensitive relay systems were applied to one 16-kv network as shown in Figure 1 and a more complicated 11-kv network as shown in Figure 2.

At each station a small grounding bank of three 5-kva distribution transformers is installed.

It can be seen that a separate type of protection is required for:

1. Radial feeders, designated by *R*.
2. Loop feeders at the source station, designated by *LS*.
3. Loop feeders at the receiving stations, designated by *L*.

Relay Systems

The diagram in Figure 3 shows the relay protection, type *R* and *LS* required for source stations such as Eagle Rock substation shown in Figure 1, and Katella and Fairview substations shown in Figure 2. This diagram shows only one radial feeder and one loop feeder. Additional feeders are exact duplicates of one of these types. Figure 4 is a schematic wiring diagram of the relays used in conjunction with the transmitting and receiving sets. Figure 5 is an internal diagram of the special fault detecting relay *IT-12*. The radial feeder relay system is the same as that described in a previous paper.

It can be seen (Figure 3) that the grounding bank consists of three 5-kva distribution transformers. The primary windings of these transformers used in Figure 1 are 16.5 kv, the secondary windings, 115 volts; and the ones used in Figure 2 are 12 kv to 120 volts.

The grounding bank secondary delta is closed by an air circuit breaker which is controlled by an over-current relay. In the event the relay protection takes longer than a predetermined time to clear a ground fault, the over-current relay will operate, thus opening this delta circuit breaker. When the circuit breaker is open a voltmeter across the delta indicates percentage ground faults. Only at the source station is there a resistor of such conductivity as to prevent resonance, thus preventing high voltages when the system becomes ungrounded.

Because the grounding banks at the various stations are small, their impedance is high in relation to the line impedance. Therefore a ground fault at any location will cause all grounding banks to produce almost the same amount of ground current. The maximum ground current depends upon the number of ground banks used in a given system when a solid ground fault occurs. The magnitude of ground fault current then will range from a minimum to this maximum, inversely as the resistance in the ground fault.

Since the line impedance is so low, the problem of discriminating by time is impossible. It therefore is necessary to use a blocking method to prevent improper ground relay action. In the two locations shown in Figures 1 and 2, carrier current sets[3] are used to send the necessary lockout signals. Pilot wires could be used for the signal channel but at the above locations the carrier sets proved more economical.

The directional ground relay type *CR-DD* is made as shown by the internal connection diagram, Figure 6. This relay is similar to a directional-controlled single-phase power directional relay except that the directional contacts have duodirectional function. When contact 8 closes to contact 10, it activates a transmitting relay sending a signal to the remote end of that circuit to lock out the tripping relays, thus preventing them from operating. When contact 8 is closed in the opposite direction, the relay is in tripping condition.

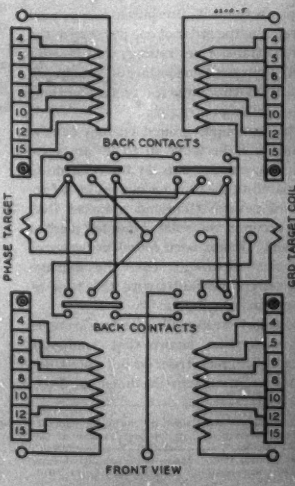


Figure 5. Internal connections of special fault detecting relay type *IT-12*

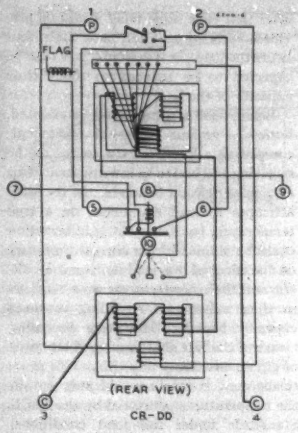


Figure 6. Internal wiring diagram of special ground relay type *CR-DD*

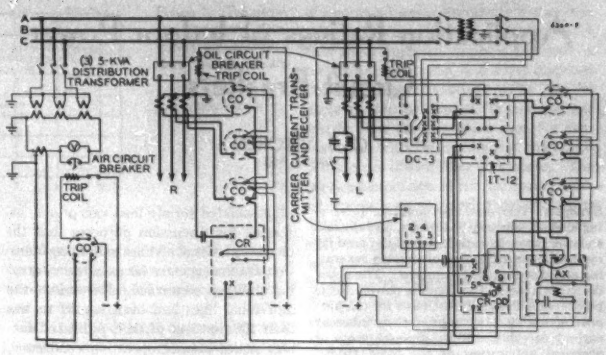


Figure 7. Receiving station relay system

Figure 7 is a diagram of the relay setup at receiving stations consisting of one radial feeder and one loop feeder. This setup is different in that there is no limiting resistor in the secondary delta circuit and a phase directional relay has been added for phase protection. The reason no phase directional relay is necessary at the source station is apparent in that any phase-to-phase short-circuit current is away from the station and not toward the station. The over-all operation of the system is simple and makes use of the fact that if fault current flows through a feeder toward a station bus, that feeder is unfaulted and should not relay. Therefore in Figures 1 and 2, ground current faults can flow toward any station in the loop feeders while phase-to-phase current can flow in the feeders only toward receiving stations. For example, should a ground fault occur on the radial feeder out of Katella, a source station, ground current will flow toward Katella on the two feeders from Orange and the two feeders from Anaheim. If a phase-to-phase occurred on this radial feeder, no short-circuit current would flow on these four feeders. If a ground fault occurred on a radial feeder out of Orange substation, ground current would flow in the two Orange circuits in the opposite direction from the foregoing case, while the current in the two Anaheim lines still would flow toward Katella. However, if a phase-to-phase fault occurred on this feeder, short-circuit current would flow toward Orange on its two circuits and none on the Anaheim lines.

This relay system will cause a directional relay to close contacts when fault current is flowing toward a station bus. If the fault is phase-to-phase it will cause the polyphase directional relay *DC-3* to close contacts, and if the fault is phase-to-ground it will cause the ground directional relay *CR-DD* to close contacts. If the fault current is of sufficient magnitude it will cause the fault detector relays *IT-12* to operate its contacts. The contacts of each of these two sets of relays are in series and energize the transmitting relay which causes the carrier set to transmit, sending a signal to the remote end of the distribution circuit to prevent the relays at that end from tripping. This is accomplished by having the receiver relay energize the lockout relay *AX*. The lockout relay short-circuits the operating coils of the over-current phase tripping relays and opens the directional control of the ground tripping relay, thus preventing the operation of the tripping relays. This is done also at the transmitting end by energizing the lockout relay directly from the transmitting relay *TR*. Figure 6 is an across-the-line diagram to show schematically the connections of these various relays.

Because the receiving substations are all unattended, it became necessary to devise a method of routine testing of the entire carrier relay circuits. The receiver relays are set to operate at two milliamperes current and the second receiver relay has a setting of five milliamperes. This second relay is used normally as a signal relay so that when reception is below five milliamperes, it will not function. Therefore, the scheme of testing must have the operator at the source substation transmit on one of the loop circuits. This will cause the signal receiver relay at the remote or receiving substation to operate, which in turn causes the transmitter of the other circuit at the receiving substation to transmit to the signal receiving relay at the source substation energizing a pilot light. This gives a positive check on carrier operation in that direction. By energizing the other transmitter at the source substation, a positive check is made for carrier transmission in the opposite direction. In Figure 1, if the transmitter is energized on the Altadena line at Eagle Rock, the receiver relays of the other two circuits should indicate proper transmis-

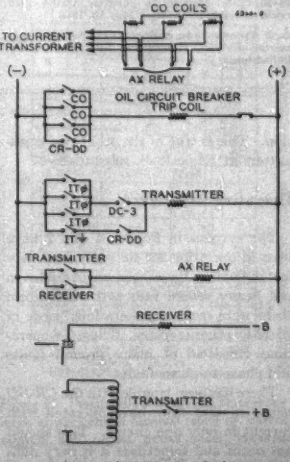


Figure 8. Across-line diagram of relay system

Application Ratings of Indoor Power Circuit Breakers

O. B. VIKOREN
MEMBER AIEE

Synopsis: Increased cost involved in serving electric power to customers, and the aim to lower rates, have accelerated the need for most efficient utilization of existing generating and distribution equipment. The paper describes a method for loading power circuit breakers on a temperature basis for the purpose of taking advantage of their inherent current carrying ability. Several years of practical application of the basic theory has proved entirely satisfactory on various types of electric equipment and has, in many cases, established considerable savings on new investments. While these savings apply to a lesser degree to circuit breakers than to other major power equipment, their application in accordance with temperature, rather than name plate rating, has put the use of new and existing facilities on an equally sound engineering basis.

AS A RESULT of the increasing need for better utilization of high-voltage line capacities, the question arose some years ago as to what maximum safe overloads could be carried on existing line equipment during emergency conditions. It is the practice to consider the firm capacity of a load distribution center as the summation of the capacities (ratings) of all associated supply lines except one, assuming for discussion purposes that the characteristics of all lines under consideration are the same, so far as current carrying ability is concerned. Heretofore, the individual lines had been loaded to less than 100 per cent of their published ratings under normal operating conditions, and slightly overloaded only during emergency. This is not to imply that rational overloading of equipment had never been practiced before; in fact, certain transformers had been operated on a temperature basis for a number of years. However, the temperature limits used were, as a rule, those which were set up for the entire industry by the AIEE, or in a few isolated cases, determined by tests on the system. Certain power circuit breakers also had been included in these tests, but a practice of overloading equipment in general, on a true temperature basis, had not been firmly established. In the proposed setup, the optimum conditions would be to operate each line normally at 100 per cent of its true rating and apply correspondingly heavier overload during emergencies, even if a small percentage of the equipment life had to be sacrificed at each occurrence. The emergencies were estimated to last for relatively short periods of time in the majority of cases, that is, a relatively heavy overload might be expected for the first two hours, but after that time some relief would be provided by load transfer, and after four hours the load per line would, as a rule, be expected to be reduced to the normal capacity of the line.

Before such a setup could be adopted, however, various pieces of equipment, comprising a line from the source to the receiving end had to be investigated; thus also, power circuit breakers. In the early attempts to load equipment on a true temperature basis, very little information could be obtained from current literature on the effect of overload on circuit breakers, and the manufacturers were cautious in their statements regarding overload capacity because they were becoming aware of the fact that, among older types of circuit breakers, only those with practically new contacts would stay within the temperatures permitted by the AIEE Standards under full load conditions. The manufacturers were fearful that overload of 2- and 4-hour durations might tend to weaken the contact structure and, in the case of most types of oil circuit

Table I

Circuit-Breaker Name Plate Ratings	Per Cent Service Factor: Copper Contacts	Per Cent Service Factor: Silver Contacts
2.4-kv and 4-kv service		
600–1,200 amperes	75	100
2,000 amperes and above	65	90
All types of metalclad switchgear		100
13-kv service		
600–1,200 amperes	80	100
2,000 amperes and above	75	90
All types of metalclad switchgear		100

1. When circuit breakers, except for metalclad units, are installed in open air, these service factors are to be multiplied by a compartment factor of 1.1, and when installed in tight compartments with no ventilation, the service factors are to be multiplied by 0.9.

2. A service factor of 100 per cent is to be used for metalclad switchgear as long as conventional installations are adhered to, or in cases where a single metal-enclosed unit is installed in an existing concrete cell with restricted air flow on three sides. Where metal-enclosed units are installed, either as a single unit or in the conventional way, but where in both cases the head room is seriously restricted, an arbitrarily chosen service factor of 95 per cent should be used. The fact that the units have tightly fitting doors should be disregarded because, where in the manufacturer's judgment extra ventilation is required, they are designed with louvers, or openings are provided in places where they are most effective. In other words, the compartment factor is one.

3. The maximum temperature of copper directly connected to circuit-breaker terminals is to be limited to 70 degrees centigrade under normal conditions, and 90 degrees centigrade under emergency conditions lasting two days or less, except for metalclad switchgear where the limits should be 80 degrees centigrade under normal conditions and 105 degrees centigrade under similar emergency conditions.

4. The maximum temperature of copper directly connected to circuit-breaker terminals is to be limited to 90 degrees centigrade under emergency conditions lasting for more than two days, except for metalclad switchgear where the limit should be 95 degrees centigrade.

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sion. This is true of the other two transmitters at Eagle Rock substation.

Operating Experience

The systems in Figures 1 and 2 have been in operation for six years, and very few difficulties have been uncovered. In one heavy severe rain and wind storm there were over 200 operations, none of which were unnecessary. These 200 operations consisted of many ground faults and phase-to-phase faults.

There has been trouble with the *CR-DD* relays in that they have operated with current in only one circuit. This should not occur and sometimes it is very difficult to adjust these relays to prevent such operation. The wave trap capacitors absorb moisture causing difficulty with the carrier operation. This seems to be the greatest cause of trouble in all carrier relay systems of the Edison Company.

With these years of operating experience it can be said that this scheme is a practical solution to the ground fault problem. A less complicated system may be developed in the future.

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1. SENSITIVE GROUND PROTECTION FOR RADIAL DISTRIBUTION FEEDERS, Lloyd F. Hunt, J. H. Vivian. AIEE TRANSACTIONS, volume 59, 1940, February section, pages 84–7.

2. NEW PILOT PROTECTION GIVES RELIABILITY, Lloyd F. Hunt. *Electrical World*, volume 106, September 26, 1936.

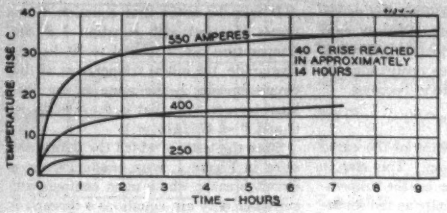

Figure 1. Temperature rise versus time curves for 500-ampere power circuit breaker

Main contacts in air

breakers, heat the oil to such an extent that the circuit breakers might catch fire if called upon to interrupt short-circuit current while in the overheated condition.

The only way really to determine what circuit breakers could do under overload conditions would be to make tests on typical units of various makes in the compartments in which they were operating.

Test, Evaluation, and Application

In view of the efforts made to provide for good housekeeping and proper maintenance of equipment, it was quite a surprise when tests revealed that the temperature rises on some of the circuit breakers substantially exceeded 30 degrees centigrade at full load (name plate rating) when tested in the "as found" condition. Some circuit breakers would not carry full load even when the main contacts were replaced with completely new assemblies obtained from stock. The loads at which the tested circuit breakers had 30 degrees centigrade temperature rise ranged from 45 per cent to 80 per cent of name plate rating in the "as found" conditions, and from 70 per cent to 100 per cent when reconditioned, depending on the type.

From the tests it could be stated quite conclusively that no oil circuit breaker with copper to copper contacts was able to carry current equal to its name plate rating without exceeding the standard 30 degrees centigrade temperature rise, except when in as good as new condition, and operating in open air or in a well ventilated compartment. Copper contacts, in particular, deteriorate after initial installation or subsequent overhauling, because of cumulative oxidization and the resulting increased temperatures.

It logically may be asked why this condition had not been discovered before tests were made. The answer is that circuit breaker ratings often exceeded cable ratings when single cable per line was used, that in the previous operating setup circuit breakers were called upon to carry full load only under rare emergency conditions, and under normal conditions the load currents were low enough so as not to make contact maintenance particularly excessive and thus did not arouse the suspicion of those in charge.

This is substantiated by the tests, and Figure 1 shows a typical example of the temperature rise of the main current-carrying contacts versus time, for three different load currents on a 15-kv 500-ampere oil circuit breaker of a type on which the main contacts are in air.

Deterioration of contacts due to cumulative oxidization, accidental burning during fault current interruption, gradual annealing and reduced contact pressure are all factors which tend to increase the temperature rise of a circuit breaker. The factor contributing the most, however, is probably oxidization. This means that in order to maintain rated temperature rise, the true rating of a circuit breaker ought to be decreased as a function of time after each reconditioning, but, since this is impractical, the ratings have been set up on an approximate basis, to secure rated temperature rise on the circuit breakers at the elapse of about one-half of the time between maintenance periods. This rating is referred to as the nominal rating.

Obviously, tests could not be conducted on all the various types of circuit breakers which are in service on the system, and they were therefore confined to eight units of the types most commonly used.

The method adopted for determining nominal ratings of circuit breakers, to be applied over a normal period between maintenance overhaulings, employs an assigned service factor and compartment factor dependent upon the circuit-breaker type, type of contact structure, and type of installation. The product of these factors and the name plate rating, will give a true rating for continuous load at which the circuit breaker is expected to have 30 degrees centigrade contact temperature rise above ambient temperature outside the breaker compartment, on the time basis explained above.

The list of service factors had to be chosen with considerable conservatism, particularly for metalclad switchgear, because operating experience with that type of equipment was considerably less at that time than it is today. In view of the fact that silver surfaced contacts are used in metalclad switchgear, and silver does not develop current-resisting oxides to the same degree as copper, experience has taught that there is less reason for conservatism with this equipment than with other types of switching equipment. The service factors now in use, excepting those of especially weak circuit breakers, are as listed below. These factors apply to circuit breakers in ventilated compartments, and are subject to modifications as stated in the notes supplementary to the list. Some of the factors recently have been increased slightly, and may be modified further if future experience so permits.

The purpose of the tests conducted on the eight circuit breakers mentioned was not only to determine the temperature versus time curves for these particular units, but also to give sufficient basic information so that the equations for such curves could be derived, and thereby a method established, by means of which the temperature rise for any combination of load and time could be calculated. The reader may sense that the entire analysis of this problem is rather involved. The practical application has been greatly simplified, however, by developing diagrams similar to Figure 2 for typical load cycles and for various types of circuit breakers.

Example: Normal* and typical emergency ratings are to be assigned to a 500-ampere 15-kv circuit breaker of the type used in the test, assuming that the ambient temperature is 40 degrees centigrade, the service

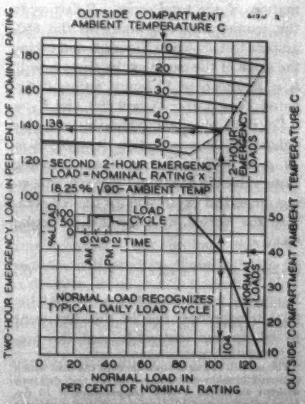
OUTSIDE COMPARTMENT AMBIENT TEMPERATURE C
TWO-HOUR EMERGENCY LOAD IN PER CENT OF NOMINAL RATING
OUTSIDE COMPARTMENT AMBIENT TEMPERATURE C
NORMAL LOAD IN PER CENT OF NOMINAL RATING
SECOND 2-HOUR EMERGENCY LOAD = NOMINAL RATING x 18.25% √90-AMBIENT TEMP
2-HOUR EMERGENCY LOADS
NORMAL LOADS
LOAD CYCLE
% LOAD
TIME
AM
PM
NORMAL LOAD RECOGNIZES TYPICAL DAILY LOAD CYCLE

Figure 2. Permissible normal and emergency loads in per cent of nominal rating on indoor oil-poor and oilless power circuit breakers

Main contacts in air

Table II

Time, Hrs	Tested Temp Rise at 550 Amp	Calculated Temp Rise at 400 Amp	Tested Temp Rise at 400 Amp
0.5	21.2	11.25	9.5
2	29.8	15.8	14.5
5	33.5	17.7	16.7
7.5	35.0	18.5	17.5

factor is 0.8, and the compartment factor is 0.9; in other words, a circuit breaker with copper to copper contacts, mounted in a tight compartment and having a nominal rating of

$$500 \text{ amperes} \times 0.8 \times 0.9 = 360 \text{ amperes}$$

Following the guide on Figure 2 the results are

$$\text{Normal rating} = 360 \times 1.04 = 375 \text{ amperes}$$
$$\text{Two hour emergency rating} = 360 \times 1.38 = 496 \text{ amperes}$$

Second 2 hour emergency rating is calculated from the formula

$$360 \times 0.1825 \sqrt{90 - 40} = 466 \text{ amperes}$$

The basic theory on operation of electric equipment on a temperature basis as used in the Philadelphia Electric Company was developed by members[1-3] of this company's engineering department. The general equation has the form

$$\theta = A(1 - \epsilon^{-at}) + B(1 - \epsilon^{-bt}) \quad (1)$$

where θ is the temperature rise, and A, B, a, and b are the equivalent of the factors which appear in the first two terms of an infinite series expressing the reaction of a thermal circuit to applied energy. These two first terms give a close approximation of the total series. Referring to the temperature rise curve in the 550-ampere test shown in Figure 1, and taking the slope of the curve at the times $t_2 = 3$, $t_3 = 6$, and $t_4 = 12$ hours, values designated $X_2 = 1.317$, $X_3 = 0.688$, and $X_4 = 0.425$ were obtained, which in turn give values for the parameters $A = 28$, $B = 12$, $a = 2.65$, and $b = 0.14$. Inserting these values in equation 1 gives the following numerical expression for the temperature rise versus time for this particular test:

$$\theta = 28(1 - \epsilon^{-2.65t}) + 12(1 - \epsilon^{-0.14t}) \quad (2)$$

It may be noted from the curve that the final temperature rise in this test went to 40 degrees centigrade, and the preceding equation also satisfies this condition for high values of t. However, as it is desirable to limit the rise to AIEE standard value of 30 degrees centigrade, the equation for that condition becomes

$$\theta = 21(1 - \epsilon^{-2.65t}) + 9(1 - \epsilon^{-0.14t}) \quad (3)$$

retaining the general shape of the curve while shifting its location. This step is justified by the tests because the temperature rise varies practically as the square of the current over the major portion of the curves, as will be seen from Table II and by referring to the temperature rises in the 400-ampere and 440-ampere tests. Following the same reasoning, the current which will cause a 30 degree centigrade temperature rise is therefore

$$I = 550 \sqrt{\frac{30}{40}} = 475 \text{ amperes}$$

In the majority of cases when dealing with overload, the question is not so much one of finding out what temperature rise a circuit breaker will have when starting "cold," as it is to determine what total temperature it will reach at a given ambient temperature after having carried a certain amount of load prior to the application of overload. After all, it is the total temperature which sets the limit at which a circuit breaker can operate safely, and once this limit has been chosen, the corresponding current can be calculated.

If

X_t represents total contact temperature in degrees centigrade as a function of time, that is, temperature rise plus ambient temperature,

A represents ambient temperature in degrees centigrade,

t represents time in hours,

θ_{1_0} and θ_{2_0} represent the initial temperature rise in degrees centigrade of the component parts of total temperature rise before application of a load whose ratio to nominal rating is R,

θ_{1_f} and θ_{2_f} represent the final temperature rises in degrees centigrade of the component parts of total temperature rise at sustained load whose ratio to nominal rating is R,

then the equation for the total temperature can be written:

$$X_t = A + \theta_{2_0} + \theta_{1_0} + (\theta_{2_f} - \theta_{2_0})(1 - \epsilon^{-2.65t}) + (\theta_{1_f} - \theta_{1_0})(1 - \epsilon^{-0.14t}) \quad (4)$$

where

$$\theta_{2_f} = 21R^2 \quad (5)$$

$$\theta_{1_f} = 9R^2 \quad (6)$$

and

$$R = \frac{\text{sustained load}}{\text{name plate current rating} \times \text{per cent service factor} \times \text{per cent compartment factor}} \quad (7)$$

It may be noted that equation 4 becomes identical with equation 3 if the temperature rise is limited to 30 degrees centigrade, the initial temperature of the circuit breaker is the same as the ambient temperature, that is, $\theta_{1_0} = 0$, $\theta_{2_0} = 0$, and $R = 475/475 = 1$.

Since the tests, of which the results are show in Figure 1, were conducted on a circuit breaker whose main contacts are surrounded by air, equations 4 through 7 are believed to be accurate enough for practical application on any type of power circuit breaker whose main contact structure is in air.

To clarify the application of equation 4, let it be assumed that the 500-ampere test circuit breaker had carried 400 amperes continuously at 40 degrees centigrade ambient temperature, that the product of the service factor and compartment factor is 80 per cent, and that it is desired to find the total temperature which the circuit breaker will reach when carrying 200 amperes additional load for two hours. Graphically, the problem is shown in Figure 3 and the numerical solution is found as follows.

Because of the fact that the circuit breaker has been carrying 400 amperes continuously, prior to the application of the 600-ampere load, and its temperature, thereby, has reached a steady state, it is immaterial what the initial temperature rises were when the 400-ampere load was first applied. Equation 4 can therefore be written as follows for the steady state condition.

$$X_t = 40 + 0 + 0 + (\theta_{2_f} - 0)(1 - 0) + (\theta_{1_f} - 0)(1 - 0)$$

and inserting the values for θ_{2_f}, θ_{1_f} and R

$$X_t = 40 + 21\left(\frac{400}{500 \times 0.8}\right)^2 + 9\left(\frac{400}{500 \times 0.8}\right)^2$$
$$= 40 + 21 + 9 = 70 \text{ degrees centigrade}$$

These values, 21 and 9, become the initial temperature rises of the component parts so far as the following two hours are

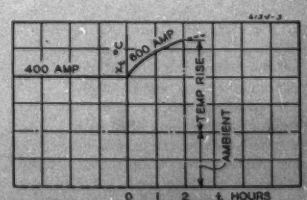

Figure 3. Total temperature of circuit breaker with 200-ampere load superimposed for two hours on 400-ampere normal load

* The normal rating is equivalent to the load which a circuit breaker can carry day in and day out without exceeding a total temperature of 70 degrees centigrade at 40 degrees centigrade ambient temperature, 60 degrees centigrade at 20 degrees centigrade ambient temperature, and 55 degrees centigrade at 10 degrees centigrade ambient temperature, recognizing the typical daily load cycle. Emergency loads equivalent to emergency ratings may be carried immediately following normal load.

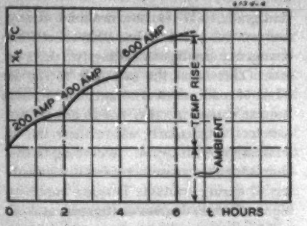

Figure 4. Total temperature of formerly idle circuit breaker after successive application of 200-ampere, 400-ampere, and 600-ampere load for two hours each

concerned, during which time the load is 600 amp. Therefore, equation 4 for that condition can be written:

$$X_t = 40+21+9+\left\{21\left(\frac{600}{500\times0.8}\right)^2-21\right\}\times(1-\epsilon^{-4.5})+\left\{9\left(\frac{600}{500\times0.8}\right)^2-9\right\}\times(1-\epsilon^{-0.28})=98.9 \text{ degrees centigrade}$$

If, however, the conditions had been as shown on Figure 4, that is, the circuit breaker had been idle and had assumed the same temperature as the surrounding air before loads of 200 amperes, 400 amperes, and 600 amperes were applied at two hour intervals, the solution would be as follows:

First two hours

$$X_t = 40+21\left(\frac{200}{500\times0.8}\right)^2(1-\epsilon^{-4.5})+9\left(\frac{200}{500\times0.8}\right)^2(1-\epsilon^{-0.28})=40+5.2+0.5$$

Second two hours

$$X_t = 40+5.2+0.5+\left\{21\left(\frac{400}{500\times0.8}\right)^2-5.2\right\}\times(1-\epsilon^{-4.5})+\left\{9\left(\frac{400}{500\times0.8}\right)^2-0.5\right\}\times(1-\epsilon^{-0.28})=40+21+2.1$$

Third two hours

$$X_t = 40+21+2.1+\left\{21\left(\frac{600}{500\times0.8}\right)^2-21\right\}\times(1-\epsilon^{-4.5})+\left\{9\left(\frac{600}{500\times0.8}\right)^2-2.1\right\}\times(1-\epsilon^{-0.28})=93.7 \text{ degrees centigrade}$$

It will be noted that by using equations 4 to 7, inclusive, and a step by step method of calculation, temperatures or ratings of oilless and oil-poor circuit breakers can be calculated for any type of load cycle, provided that in the first case, the load currents are known, and in the second case, the temperature limits are chosen.

For oil circuit breakers with all of the contact structure under oil, the same reasoning as above can be applied to the test results obtained on these types, and the total temperature of the contacts can be expressed by the equation

$$X_t = A+\theta_i+\theta_{2_0}+(\theta_{2_f}-\theta_{2_0})(1-\epsilon^{-t/\beta}) \quad (8)$$

where

$$\theta_i = 4.5R^2 \text{ for } t = \text{two hours or more} \quad (9)$$

$$\theta_i = 7.5R^2 \text{ for } t = \text{less than two hours} \quad (10)$$

$$\theta_{2_f} = 25.5R^2 \quad (11)$$

and

X_t represents total contact temperature in degrees centigrade as a function of time, that is, temperature rise plus ambient temperature

A represents ambient temperature in degrees centigrade

t represents time in hours

θ_i represents contact temperature rise above oil temperature in degrees centigrade

θ_{2_f} represents final oil temperature rise in degrees centigrade under load whose ratio to nominal rating is R

θ_{2_0} represents initial oil temperature rise in degrees centigrade before application of load whose ratio to nominal rating is R

While some of the temperature limits now in use when rating circuit breakers have been stated in connection with the service and compartment factors, the selection of these and others needs to be justified.

The various tests were conducted on circuit breakers mounted in compartments which were either tightly closed with doors or partially ventilated, and the ambient temperature on which the temperature rises are based, was taken outside the compartment to make the basis consistent. For circuit breakers in tight compartments with no ventilation, it was found that the ambient temperature inside the compartment and thus the circuit breaker total temperature was approximately five degrees centigrade higher than for the same circuit breaker with the same load in a compartment with some ventilation. Based on this observation, the rating for circuit breakers in tight compartments should be approximately 0.9 times the rating of circuit breakers in ventilated compartments. Further, since the ambient temperature inside the compartment was approximately five degrees centigrade higher than outside the compartment, a circuit breaker installed on a structure without compartmentation, with little or no restrictions to the air flow, could carry approximately 1.1 times the load of the same circuit breaker when installed inside a ventilated compartment.

Table III. Average Ambient Temperature

Calculated (Deg C)	Use (Deg C)
17.5–22.5	20
22.5–27.5	25
27.5–32.5	30
32.5–37.5	35
37.5–42.5	40

Ambient Temperatures

Before any rating based on temperature can be assigned to a circuit breaker, it is necessary to arrive at an average ambient temperature at its location. In attended places, this is done by taking daily thermometer readings in the room every four hours during two seasons of the year, one season termed summer lasting from April through October and containing 214 days, the other termed winter lasting from November through March and containing 151 days. The daily maximum readings on the same thermometer are added over each of the two seasons and divided by 214 and 151 days respectively, thus arriving at a daily average ambient temperature for the summer, and likewise for the winter. If several thermometers are located in the same room the highest value calculated on the above basis is considered the average ambient temperature for that room. However, in any event, for the purpose of simplifying rating calculations, the average is rounded off as shown in Table III.

Continuous and Normal Load Conditions

Both terms cover day in and day out operation, except that the latter recognizes the typical daily load cycle for the individual problem.

The temperature rise of a circuit breaker is, as shown in Table II, nearly proportional to its I^2R loss. However, oxidization produces a steadily increasing contact resistance, particularly on copper to copper surfaces, and thus an increasing loss and temperature rise. If the total temperature is held constant and the time involved is not too long, this temperature will produce the same rate of oxidization, whether it is a result of high ambient temperature and low temperature rise, or vice versa. To clarify, compare the values in Table IV where it is assumed that under condition A, two identical circuit breakers are operating at different loads, at different ambient temperatures, but at the same total temperature when initially put in service. For a while the contacts are going to oxidize at the same rate, and let it be assumed that

after some time the contact resistance has increased 20 per cent. While initially there was no difference in total temperature, this no longer is true as the resistance increases with time, even though the ambient temperatures and the loads are held constant. This is shown under condition *B*.

Under conditon *B* it will be noted that circuit breaker 1 is four degrees centigrade hotter than circuit breaker 2. It will get progressively hotter, in fact, the heating is actually somewhat worse than indicated in the tabulation because the two circuit breakers will oxidize at different rates as soon as the smallest difference in total temperature appears.

From this analysis the conclusion can be drawn that, for circuit breakers operating on a continuous or normal basis, the allowable total temperature limits should be lowered with decreasing ambient temperature, although not necessarily in direct ratio. Stated in another way, the permissible temperature rise should be restricted with decreasing ambient temperatures. This restriction has been chosen as one-half of the amount between the actual ambient temperature and 40 degrees centigrade, as long as the ambient temperature is below the latter value. At 40 degrees centigrade ambient temperature and above, the total temperature has been limited to 70 degrees centigrade because, so far, no higher value appears justified under normal load conditions. It will be noted under condition *C* in Table IV that, in order not to exceed the permissible total temperature limits of circuit breaker 1 while operating continuously at loads exceeding its nominal rating, several remedies can be employed. These will be considered in the same order as tabulated under condition *C*.

Remedy 1. Reduce the load current. This may or may not be possible and would mean revenue loss unless it could be picked up on other less loaded circuits.

Remedy 2. Reduce contact resistance below original value. This means either to rebuild the circuit breaker for the next higher current rating, which generally is feasible only on circuit breakers rated below 1,200 amperes, or to replace the circuit breaker with one of higher rating. (It has been assumed that the new contact structure would have 20 per cent less resistance than the original in order to fit into this picture.)

Remedy 3. Reduce the ambient temperature by means of ventilation. As a result of ventilation, the compartment factor will change, which in turn will increase the nominal rating, and thus reduce the percentage overload (shown in parentheses, Table IV) for the same actual current. Thus, in this example, the contacts could, at least on a theoretical basis, be permitted to deteriorate until their resistance reached 150 per cent of the original before permissible temperature limits would be exceeded. Since the needs for overhauling, under the assumed conditions, would seem to be only a matter of time, the contacts might just as well be reconditioned and at the same time silver surfaced, which would permit carrying the same ampere load without resorting to drastic reduction of ambient temperature. (Remedy 4 refers to this alternate condition. Economy, of course, will dictate which of the two steps should be taken, because ventilation may in some cases be required for other equipment in the same room.)

Remedy 4. Recondition contacts. As already indicated in the preceding paragraph, reconditioning of contacts combined with silver surfacing proves as effective as, and is often much simpler than, any of the other remedies discussed, because it does not necessarily involve extra capital expenditure or loss of revenue. Since the silver surfacing will change the service factor, which in turn will increase the nominal rating, the percentage overload actually will be less for the same ampere load. (Figure in parentheses refers to this.) The same reasoning can be applied to circuit breaker 2 for silver surfaced contacts.

Silver surfaced contacts have much less cumulative oxidization than copper contacts because silver oxide is a relatively good conductor, while copper oxide is a relatively poor one. For this reason the service factors, determined on the basis of the tests, are higher for silver than for copper contacts. While all but the earliest tests actually were conducted on reconditioned circuit breakers, as good as new copper contact assemblies were used, and during the relatively short durations of the tests, these assemblies had practically the same contact resistance as silver surfaced contacts, although with time, they would deteriorate much more rapidly.

Short Time Emergency Conditions, Maximum Duration Two Days

As a result of the fact that contact oxidization under short time emergency overloads will be considerably less than that during long time overloads, 90 degrees centigrade total temperature limit at any ambient temperature has been chosen for emergency conditions lasting two days or less. This is on the safe side so far as effect of oxidization is concerned, but has been so chosen in order not to anneal the contacts, particularly where these are of laminated brush types. According to the circuit breaker manufacturers, the annealing of spring contacts is quite rapid at higher than 90 degrees centigrade, and oil will begin to smoke at about 100 degrees centigrade. Therefore, in order not to impair the interrupting ability of power circuit breakers while in over-heated condition, the 90 degree centigrade total temperature limit seems to be wisely chosen. This excludes metalclad switchgear. If oilless circuit breakers are used, 105 degrees centigrade is believed to be permissible. If oil circuit breakers are used in metalclad gears, special consideration will be given to the problem.

Since the 90 degree centigrade limit applies to emergencies of two days or less, the question may be raised as to what load a circuit breaker can carry for two days if the 90 degree centigrade limit is reached, for example, within the first two hours. Referring to equations 4 and 8, these take the form $X_t = 30R^2 + A$ under this condition. Solving for R, realizing that X_t already has reached 90 degrees centigrade and may continue at this value up to two days, the answer is

$$\text{Nominal rating} \times \sqrt{\frac{1}{30}(90 - A)}$$

Long Time Emergency Conditions

Under long time emergency operation lasting more than two days, the total

Table IV

Condition	Circuit Breaker	Per Cent Resistance of Contacts	Continuous Load in Per Cent of Nominal Rating	Ambient Temp, C	Temp Rise, C	Total Temp, C	Remarks
A	1	100*	129	20	50	70	Exceeds permissible temp rise
	2	100*	100	40	30	70	Permissible total max temp
B	1	120†	129	20	60	80	Exceeds permissible total max temp
	2	120†	100	40	36	76	Exceeds permissible total max temp
C	1	120†	115	20	40	60	Limited by permissible total max temp
	1	80	129	20	40	60	Limited by permissible total max temp
	1	150†	129 (115)	0	50	50	Limited by permissible total max temp
	1	100‡	129 (115)	20	40	60	Limited by permissible total max temp
	2	100‡	100 (90)	40	30	70	Limited by permissible total max temp

* New or reconditioned copper contacts. † Oxidized copper contacts. ‡ Silver surfaced copper contacts.

temperature limit for power circuit breakers has been chosen at 80 degrees centigrade in order to avoid excessive contact oxidization. Similarly, metalclad switchgear with oilless circuit breakers is limited to 95 degrees centigrade. In metalclad gears, the contacts always are silver surfaced, and springs which furnish contact pressure are not depended on so far as current carrying ability is concerned. Again oil circuit breakers in metalclad gears are given special consideration.

Temperature Limits of External Connections

The total temperature limits for external copper directly connected to power circuit breakers have been so chosen that heat will not be carried into the circuit-breaker contacts. When apparent deviations occur at low ambient temperatures, they are not believed to be serious, as the circuit-breaker terminal structure has been found to act as a choke. The values are stated in Table I.

In the preceding discussion, except where applied to metalclad switchgear, the conventional 30 degrees centigrade rise over 40 degrees centigrade ambient temperature has been assumed in referring to circuit-breaker name plate ratings. Since the name plate ratings for metalclad switchgear are based on 45 degrees centigrade rise over 40 degrees centigrade ambient temperature, the temperature limits chosen under overload conditions for this type of equipment have been raised by 15 degrees centigrade, as compared with the limits applying to other types of switching equipment. Except for this difference, the same formulas and procedure are used on all types of indoor power circuit breakers.

Conclusion

The preceding discussion is believed to be comprehensive enough to enable those who have not yet tackled the problem of loading circuit breakers on a temperature basis to do so without difficulty. The basic problem is the same for all users, and while some of the details may vary, these details should be relatively easy to collect once the requirements are known.

In case of new circuit breakers, the calculated normal and emergency ratings may exceed name plate values by moderate amounts depending on the physical arrangement and the ambient temperature. On older types of circuit breakers, however, the name plate values will seldom be exceeded unless the units are equipped with silver surfaced contacts and ambient temperature, as well as the physical arrangements, are favorable.

The specific method described has been used on circuit breakers for several years on the Philadelphia Electric Company system and has given results which are believed to be entirely safe. The same general method also has been applied to other types of major power equipment and has resulted in considerable savings on capital investments. These savings have contributed to the maintenance of low rates in spite of the steadily rising costs involved in serving electric power to customers.

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Power System Development for Service to Hanford Plutonium Plant

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EARLY IN 1943 a number of engineers in the Bonneville Power Administration were informed of a new "mystery load" which was to be added to the BPA system. Later this load became known as the Hanford Engineer Works of the Manhattan District. We, of course, were warned that the new load was one of the war's top secrets. The product to be made, about which no one seemed to know anything, the location of the plant and its general arrangement, the amount of power to be taken by the plant, the location of the transmission lines which were to supply it, and the additional important fact that the power to be supplied had to have the utmost reliability were subjects which were not to be discussed unless absolutely necessary. It is our feeling that all these secrets were well-kept. For while BPA engineers had the responsibility of arranging their system to provide reliable service to this new load, there were times when we despaired of ever obtaining sufficient general technical information regarding the apparatus to be used by the Hanford Engineer Works to make possible the best co-ordinated system design.

At the time this new load first was considered on the BPA system slightly more than one year of war had passed. Materials and labor were critical, and the system had started serving many large war loads, including the reduction of aluminum and power for shipyards. Commitments also had been made to supply power to other large war factories, the plants for which were still under construction. A number of calculating board studies had been made previously of the transmission system including these future loads, and it was realized that the transmission system, heavily loaded as it would be, could not supply the type of reliable service which would be required by the new "mystery load." Accordingly, it was decided to determine by a series of a-c calculating board studies what system additions and changes would be necessary in order to obtain a reliable source of supply to the Hanford Engineer Works' load. These studies were started and included load-flow diagrams, transient stability studies, and relay studies, so that all possible contingencies could be taken care of.

Location of the Hanford Engineer Works' Load on the BPA System

Geographically, the BPA's transmission system serves three major load areas —the Puget Sound, Portland, and Spokane areas. Figure 1 indicates the geographic location of 230-kv and 115-kv transmission lines, major substations, and generating stations as of June 1946.

The system peak load during the war was 1,427,000 kw. But in February 1943, when the Hanford Engineer Works first

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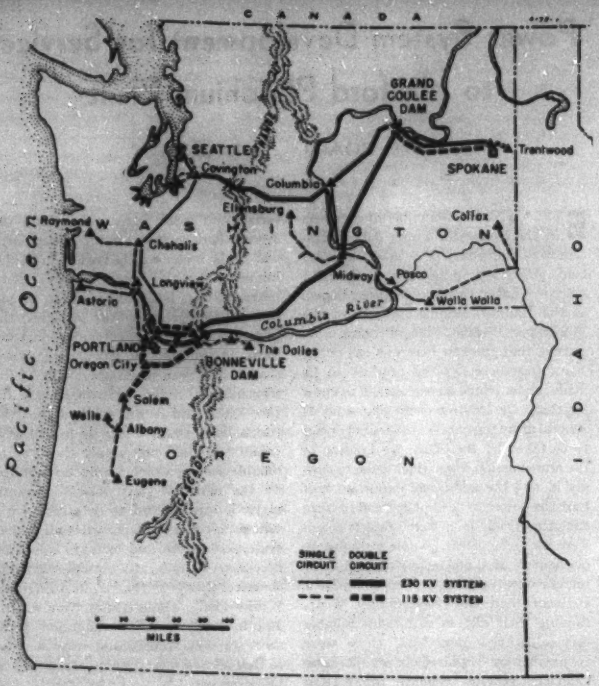


Figure 1. Bonneville Power Administration 230-kv and 115-kv transmission grid

was being considered as an additional load, the BPA system had not grown to its present size. A simplified schematic diagram of the BPA 230-kv transmission system as of February 1943 is indicated in Figure 2. This diagram shows a 230-kv loop with two large generating stations, Grand Coulee and Bonneville, and two large load centers, the Portland area and the Puget Sound area, connected to the loop. At this time there were three 108,000-kva generators installed at Grand Coulee and four 60,000-kva generators installed on the 230-kv system at Bonneville. But before the Hanford Engineer Works' load would be able to start operation, there would be eight Grand Coulee generators operating with two new 230-kv lines to Spokane and a large load at Spokane connected to the system.

The Grand Coulee generating station is constructed and operated by the United States Bureau of Reclamation; the Bonneville Power Plant is constructed and operated by the United States Army Engineers; and power from these two stations is transmitted to load centers over the transmission system of BPA. Two parallel 230-kv transmission lines connect the two generating stations through an intermediate switching station at Midway which is 100 miles from Grand Coulee and 134 miles from Bonneville. The Hanford Engineer Works' load was to be supplied from Midway, as this station had a source of supply either from Grand Coulee through two 230-kv lines or from Bonneville through two 230-kv lines.

The Problem

At that time the process to be used at the Hanford Engineer Works never had been tried fully so that knowledge of how it would work was very limited. In view of this lack of information and present-day knowledge of the destructiveness of atomic bombs, it is not surprising that extreme precautions were taken to maintain a source of supply of power to the load. We now know this power drove large pumps to supply cooling water to the uranium piles, and now can understand that the loss of power for even a short time might have brought about serious operational difficulties. Accordingly, it was decided, in addition to other less stringent reliability requirements, that the BPA system should be arranged to maintain power supply to Midway substation even for the remote probability of simultaneous or near simultaneous faults on both Coulee–Midway lines.

However, the following limitations were found with the 230-kv system as shown in Figure 2:

1. When all new loads and generation had been added to the system, loads in the Puget Sound and Portland areas would be very large in comparison with the transmission capacity, so that any double-line-to-ground fault on the Coulee–Covington line or on a Coulee–Midway line would result in the system being unstable. It would break apart, and in so doing would cause low voltage at Midway which was considered dangerous to the Hanford Engineer Works' process.

2. Power normally flows from Grand Coulee to Bonneville and the Portland area. After the system breakup occurred, with Grand Coulee separated from Midway, there was not sufficient generation at Bonneville to supply both the Portland area and the Midway loads so that the frequency and voltage at Midway would drop rapidly. Such drop in frequency also was considered dangerous to the Hanford Engineer Works' process. Similar difficulties would be encountered in case of a simultaneous fault on both Coulee–Midway lines.

3. At the beginning of the war, Grand Coulee had only one generator installed. Before August 1944 when the Hanford Engineer Works' load was to be energized, there would be eight generators installed with a maximum overload capacity of approximately 930,000 kw, and if all 230-kv lines and eight generators were to be connected to the same bus the short-circuit duty on 230-kv circuit breakers would approach 5,000,000 kva. Existing circuit breakers had an interrupting rating of 2.5 million kva while the largest available breaker, which was developed after the war started, had only a 3.5-million kva interrupting rating. Accordingly, the Grand Coulee bus had to be split up, and it was decided after considerable study that more reliable service could be supplied to the Hanford Engineer Works if one Coulee–Midway line was to be connected to each of the two new busses at Grand Coulee. This design of the Grand Coulee bus, which utilizes an interleaved arrangement of the transmission lines on two busses, has been covered in a previous paper.[1]

4. It already has been indicated how the system load, generation, and transmission lines had grown since the start of the war. Orders for high-speed carrier-current relaying had been placed for each end of all major 230-kv lines, but because of higher priorities of Army and Navy equipments, not one of some 22 sets ordered had been delivered. Without high speed clearance of faults at both ends of a faulted 230-kv line as provided by these relays, the system could

not be made stable without a greater number of reinforcements being required than otherwise would be the case. All such reinforcements, of course, had to be justified to the War Production Board because of shortages of critical material and labor.

Solution of the Problem

Extensive and intensive studies were conducted to determine the minimum system additions needed to obtain reliable service. Over 150 transient stability studies were made using several bussing arrangements at Grand Coulee and assuming faults at various locations on the system. The transmission system as shown in Figure 3, which finally was selected as satisfying the Hanford Engineer Works' load requirements for reliability as well as having sufficient capacity to supply other system loads, consists of the 230-kv loop with generation supplied at two points, while major loads are supplied from the loop at five other points. System characteristics were determined during transient stability swings following the clearance of a faulted line to be certain that relays would operate correctly when called upon to do so during these transient swings as well as during the faults. In this respect the war had forced transmission line loadings that were very high, and it was found that standard carrier type relays on some lines had to be modified before they would be completely satisfactory.

Because of the transmission loop arrangement, it was found that out-of-step blocking was undesirable, for instability might be initiated between any two major substations depending on the fault location, the initial system load division, or generation division, as well as circuit breaker and relay operating time. If such out-of-step operation did occur as a result of any cause, it was necessary to make certain that the system breakup would not produce low frequency or excessively low voltage at Midway except that low voltage would occur unavoidably for the few cycles (five to ten) between the time when a fault first occurred near the Midway bus and when it was cleared.

System Changes Needed

As a result of the foregoing and other studies, the following system changes and additions were made from February 1943 (Figure 2) to August 1945 (Figure 3). Important steps also are listed which are not shown easily on Figure 3.

1. Change in bussing arrangement at Grand Coulee.[1]
2. Addition of Coulee–Covington line number 2.
3. Arrangement for bus tie and bus sectionalizing breakers at Midway. Power to Hanford Engineer Works fed from both ends of the bus to prevent outage in case of a bus fault at the Midway substation.
4. Installation of carrier relays on all 230-kv transmission lines. Priority assistance to obtain delivery was needed most as most of the sets previously had been ordered.
5. Installation of a transfer tripping scheme at Coulee, Midway, and North Bonneville to provide an alternate source of supply from Bonneville generating station without drop in frequency or low voltage in the event of a double line outage of the two Coulee–Midway lines. (Until installation of Columbia–Midway 230-kv line.)
6. Installation of Columbia switching station (in Coulee–Covington lines) and Columbia–Midway 230-kv line.
7. Special relay studies.

(a). Resulting in modification of carrier relays.

Figure 2. Schematic 1-line diagram of BPA 230-kv system in February 1943

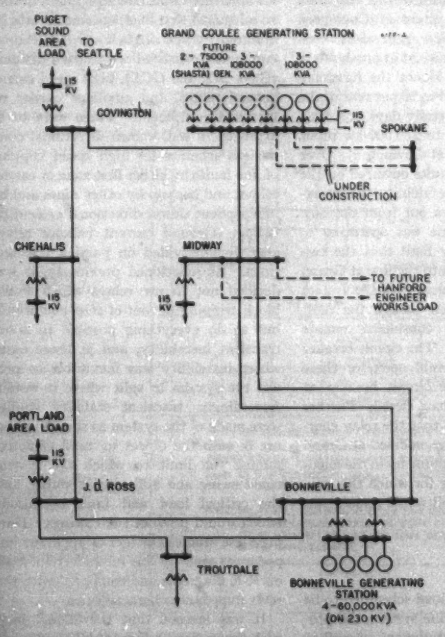
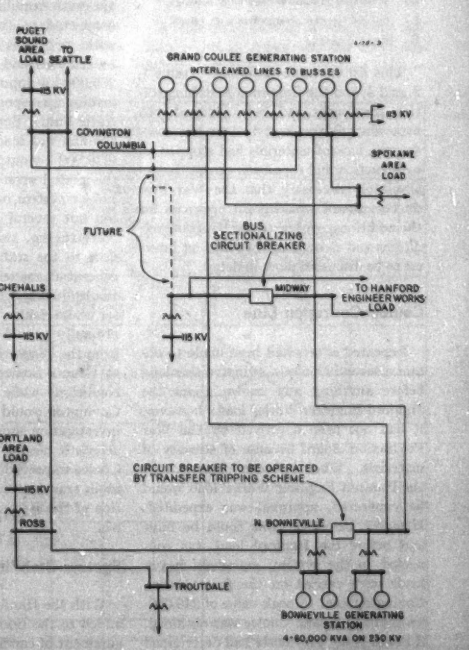


Figure 3. Schematic 1-line diagram of BPA 230-kv system in August 1944, approximate time when Hanford Engineer Works started operations



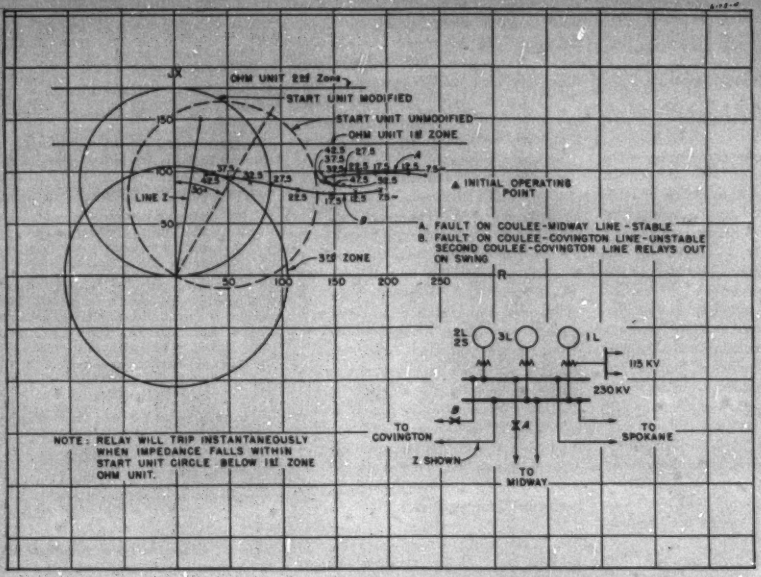


Figure 4. Impedances seen by Coulee end *GCX* and *HDX* relays in Coulee – Covington line during stability swings

(*b*). Resulting in nonstandard relay settings.

(*c*). Special backup arrangements on relays.

8. System tests.

This list is rather imposing. Items 1, 2, and 4, and the Columbia switching station previously had been planned, but even though the load had grown enormously, lack of materials had stopped all construction and expansion except that so absolutely necessary that the War Production Board would grant priorities for the additions. A few of the foregoing additions and changes are of sufficient interest to be discussed more in detail.

Coulee–Covington Line

Repeated efforts had been made to obtain a second Coulee–Covington line long before anything was known about the Hanford Engineer Works' load; however, it had not been approved by the War Production Board because of scarcity of materials. When it became known that the Hanford Engineer Works' load would be connected, approval was expedited. However, before this line could be built and before the Hanford load was connected to the system, extremely heavy loads were carried on the first Coulee–Covington line. A peak value of 240,000-kw input at Grand Coulee was obtained. A board study previously had determined the static-stability limit of this line when connected to the system at Covington with two 108,000-kw generators connected at Grand Coulee at approximately 265,000-kw input. Hence the foregoing loading corresponded to 90 per cent of the static limit. For literally days at a time the line was loaded to 230,000-kw input (210,000-kw output at Covington). Over this period several faults occurred on the 115-kv system in the vicinity of Covington but several miles out from the bus. Nevertheless, the line was operating so near to the stability limit that the two generators connected to the line at Grand Coulee lost synchronism with the system for these faults, even though the fault normally would be considered remote from the generators. The circuit breaker at Grand Coulee would open for these conditions while the circuit breaker at Covington would remain closed. Further investigation showed that the relay characteristic needed to be modified at Grand Coulee to prevent tripping up to the maximum transient swing for which this portion of the system still would remain stable.

System Stability

With the Hanford load scheduled to be added to the Bonneville system, the procurement of carrier equipment, as well as all other materials and equipment needed to safeguard that load, became greatly facilitated. The original carrier relaying equipment consisted of standard distance relays (*HZ* and *GCX*), high speed carrier ground relays, and auxiliary carrier relays and equipment. These were to be arranged in well-known directional comparison schemes for high speed tripping of line faults by either first zone or carrier relays, and backup by other zones and by independent slower directional ground relaying. Ground current balance relays also were provided on parallel line sections. As mentioned previously, it was decided not to use relays which would block tripping on out-of-step conditions, but to do everything possible to avoid transient instability, and in those cases where instability was inevitable to permit the system to split where it would. Accordingly, transient stability studies were made of the system as shown in Figure 3, with the object in mind of determining the limit to which the system could swing and still remain stable, and the critical load and fault conditions which would produce such swings. During these studies the loci of apparent impedances seen by line relays were plotted on R-X diagrams and compared with the relay impedance characteristics.

It was learned that the 230-kv loop with generation at some points and loads

at other points would produce complicated loci of apparent impedances seen by line relays during these transient swings. An example of this is shown in Figure 4, on which is drawn the characteristics of a modified start unit and the unmodified start unit (shown dotted), for the *GCX* and *HDX* relays located at Grand Coulee in a Covington line. The loci of impedances, as seen by the relay during two transient swings, are drawn on this figure. Curve *A* corresponds to a fault on a Coulee–Midway line which after clearing was found to be stable, but the locus very closely approaches the unmodified circle before it turns away. The reversal of direction of this characteristic indicates that transient stability could be maintained by the system provided the relay does not trip. If the impedance had moved within the start unit circle, undesirable instantaneous tripping would be indicated. Curve *B* corresponds to a fault on one Coulee–Covington line, which after clearing was found to produce instability. It will be observed that the relays in the remaining Coulee–Covington line will trip this circuit when the apparent impedance has progressed until it is within the start unit circle. Numbers on each curve represent cycles elapsed after the fault first occurred; the first point was at 7.5 cycles because of calculating board technique. In all these studies, the fault was assumed cleared at both ends in five cycles through use of carrier relaying and 3-cycle breakers. As a result of these studies, the start unit was changed to the foregoing modified 90-degree characteristic instead of the standard 60-degree characteristic as shown dotted, since the 90-degree angle conforms more closely to the average impedance angle of BPA 230-kv lines ($81\frac{1}{2}$ degrees) than the 60-degree angle.

Another example of the transient impedance characteristics of the system, in this case compared with the *HZ* impedance relays at the Midway end of a Coulee–Midway line is shown in Figure 5. Curve *A* represents the impedance seen by the relay for a fault on the other Coulee–Midway line and is stable since the curve reverses direction. The curve actually progresses into third zone tripping (modified to be nondirectional) except that there is a time delay of 45 cycles before actual tripping can occur, and the system has moved out of danger before the necessary time can elapse. The directional element eliminates the possibility of the second zone tripping during this period.

Curve *B* shows corresponding values for a fault on a Coulee–Covington line which was unstable. It would appear that this relay also would trip; however, analysis of other relays on the system shows that the system breaks up between Coulee and Covington and between Midway and North Bonneville. Hence Hanford is left with power supply from Grand Coulee.

In Figure 5 it may be observed that the average reach of the second and third zones is rather short, being approximately 120 per cent of the line section. These were reduced in order to avoid tripping on transient swings from which the system can recover. These swings are shown in the figures as impedance loci which reverse direction, and it was to avoid having these swings get within the tripping areas for any appreciable time that the second and third zone areas were reduced.

In order to permit the reduced settings mentioned and at the same time obtain as much reach as possible for third zone backup time delay relays, these relays were made nondirectional. By this means the third zones of all breakers on a bus provide backup for any particular breaker, rather than depending upon remote breakers. They are better able to perform this function with the necessary reduced settings because they are one line section closer to the fault, and backup tripping tends to be localized to the affected bus section.

Special Backup Relaying

A time delay backup arrangement has been added in major stations which has definite advantages in meeting the re-

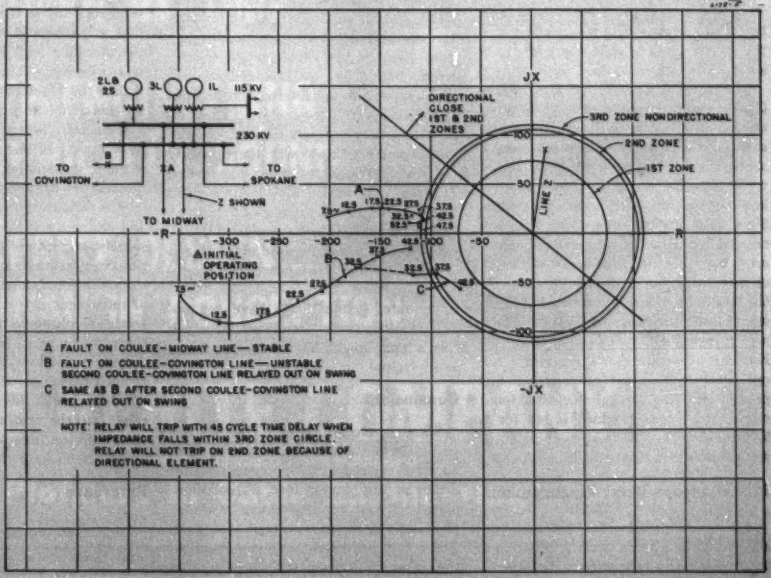


Figure 5. Impedances seen by Midway end *HZ* relay in Coulee–Midway line during stability swings

quirements of the system. This scheme, in the event that a breaker fails to open, operates the bus differential auxiliary relay associated with that breaker in 6 to 12 cycles after the breaker trip coil has been energized. (These are 3-cycle breakers.) This scheme tends to isolate trouble before second zone operations occur in other substations and is consistent with the attempt to localize backup tripping to the affected station as much as possible. Another important aspect of this backup feature, in cases where several sources can feed into a faulted line, is that it does provide backup where the normal type of overlapping directional impedance relays with time delay would fail to do so. The fact that the currents in the unfaulted lines are small percentages of the total fault current, because of multiple feeds, makes the impedance apparent to relays in the unfaulted lines often much larger than the settings of their backup zones. Since the normal backup scheme is not suited to the conditions, it was decided to use the special scheme described, the operation of which is initiated directly by the failure of the breaker to trip in the faulted line.

In order to provide more reliable service to the Hanford Engineer Works, at Midway substation only, the second zone distance trip circuits are connected to auxiliary relays arranged to trip any selected group of breakers. Since any second zone operation at Midway probably would be accompanied by system instability, this arrangement was made so that the system could be split to provide service to Midway from at least one line.

The third zone trip circuits of the Coulee and Bonneville lines at Midway are wired to trip one of the two bus differential auxiliary relays. The selection of the particular bus differential auxiliary to be tripped is made by directional relays on the bus sectionalizing breaker. Since both Midway–Bonneville lines are tripped by either bus differential auxiliary relay, this final backup arrangement of the Coulee lines. Similar backup for the Hanford lines is provided by instantaneous overcurrent relays which are operated by the sum of the two Hanford line currents. These relays cut out the third zone trip circuits but produce tripping through the directional relays and a timer, which is set for a longer time than the third zone delay of relays on the Hanford circuits.

Miscellaneous Relay Arrangements

A 1-cycle time delay has been added to all ground carrier trip circuits to decrease the possibility of false tripping because of gap flashover in carrier sets or sequential pole operation of oil circuit breakers.

Overcurrent fault detectors have been added in the first zone and carrier trip circuits of all the relays on the Hanford loop and many on the Bonneville system to prevent tripping caused by loss of potential.

Transfer Tripping Scheme

Certain network analyzer stability studies showed that the loss of both Coulee–Midway lines, before the installation of the Columbia–Midway line, during a critically heavy load period might result in system instability, that is, Coulee would run ahead of Bonneville and separate from the Portland area. As a result of this, Bonneville would be loaded heavily by the Portland area with resultant low voltage and frequency at Midway. To safeguard against this contingency, a bus sectionalizing breaker has been installed at North Bonneville (Figure 3) and a transfer tripping scheme arranged which can be used to isolate two Bonneville generators on the lines to Midway whenever both Coulee–Midway lines are opened.

This scheme is designed to operate as follows. If either line breaker is opened at Coulee, one of two audio tones is transmitted over the line carrier relaying channel to Midway. At Midway, tone relay contacts and pallet contacts on the Coulee breakers are arranged so that whenever both Coulee lines are opened at either end an auxiliary relay will initiate the transmission of two additional tones, both over the two carrier relaying channels to Bonneville. At Bonneville the audio components are filtered and brought to their respective tone relays. These relays have their contacts in series, and are also in series with a power directional relay, which is closed for power flow toward Midway, and with a 6-cycle time delay relay. This arrangement was made to prevent any possible misoperation of the transfer trip relays because of arcing on disconnects, which can cause the tone relays to operate.

To date, system loads have not approached the critical condition for which this scheme might have been necessary, and it actually is not in service.

Conclusions

Since the inception of the Hanford Engineer Works' load on the BPA system, no change on the 230-kv system or addition of any importance was contemplated without a consideration of its effect and the requirements of that load. The result has been the development of the afore-mentioned transmission and relaying system which was designed to supply continuous service to the Hanford Engineer Works, if necessary at the sacrifice of other loads on the system.

The extreme contingencies resulting from line faults, bus faults, or circuit breaker failure for which the system was designed have not occurred. The worst of this type which has occurred was a simultaneous outage caused by lightning of both Midway–Grand Coulee lines. This occurred twice in May 1946. However, the system was loaded lightly at the time, so that these faults, although severe, were not equal to the worst condition for which the system was designed. The Hanford operators noticed the voltage dip at the time, but they continued to operate normally, apparently without ill effects. The transfer tripping scheme was not in service because of a previous determination that it would be unnecessary under present system conditions, that is, with the Columbia–Midway line in service.

A more severe condition, not a result of a line fault, occurred in March 1946, when the excitation was lost accidently on five Grand Coulee generators, all that were operating at that time, and they pulled out of step from the rest of the system. The result was a drop in frequency to 94 per cent and in voltage to 72 per cent of the normal. Design information on the pumps and motors at Hanford indicates that even at this lowered voltage and frequency, sufficient power could have been supplied to keep the pumps operating. However, during this disturbance the pumping load was taken over automatically by a standby source of power within the Hanford area, thereby avoiding this critical test of apparatus.

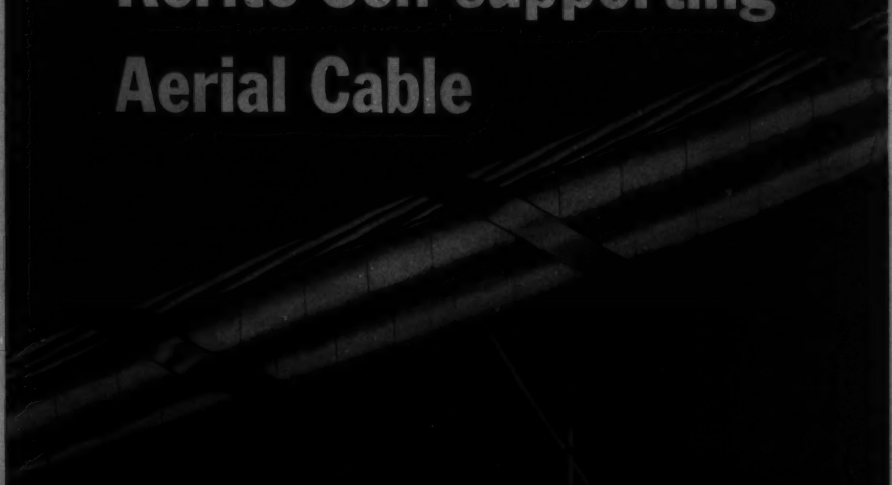
Numerous other line outages, caused by a variety of line faults, have occurred without incident at Hanford other than momentary voltage fluctuations.

It is difficult to evaluate a transmission and relaying scheme when the goal is absolute continuity of service. Practical design considerations have been based on assumptions of very severe conditions, many of infrequent occurrence, through which service would have to be maintained, but there are always a number of imaginable disasters which unavoidably would result in loss of service. Generally speaking, it is believed that this scheme, as incorporated into the system, has met and probably will continue to meet the requirements of this load.

Reference

1. An Analysis to Determine the Optimum Bussing Arrangements and Transmission Capabilities at Grand Coulee, B. V. Hoard, G. W. Bills. AIEE Transactions, volume 63, 1944, pages 1259–64.

Kerite Self-supporting Aerial Cable



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KERITE ENGINEERING—
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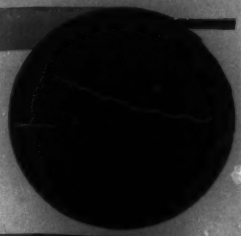
DU MONT CATHODE-RAY *Oscillography*

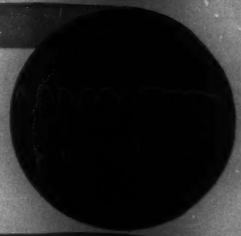
PLAYS AN IMPORTANT ROLE IN INDUSTRY

FENCE-CHARGING EQUIPMENT



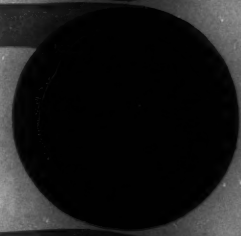
In designing or testing devices for supplying short electrical shock pulses to a fence conductor, it is essential to know the maximum voltage, shape and duration of each pulse, as well as the repetition rate. The Type 247 Cathode-ray Oscillograph is ideal for this application.

POWER EQUIPMENT



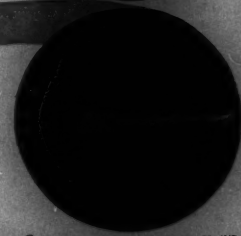
A detailed examination of the closing action of relay contacts may easily be made when using a Type 247 Oscillograph. This will reveal whether the contact closing is positive or subject to rebounce. The duration of the entire bouncing period can be accurately determined by superimposing time markers on the applied signal, and the effects of corrective adjustments may be instantly observed.

AUDIO AND VIDEO AMPLIFIERS



There is no quicker way to determine phase, frequency and amplitude distortion in an amplifier than by applying a square-wave signal to the amplifier input and visually observing the output waveform. Both the input and output signal waveforms may be viewed simultaneously on the Type 5SP Cathode-ray Tube when driven by two Type 208-B, 241, 247 or 248 Oscillographs, or most combinations of these types.

ACOUSTICS



By using a Type 208-B combined with a Type 215 Sweep Generator or by using a Type 247 Cathode-ray Oscillograph when conducting a reverberation test, accurate information may be obtained as to the damping time of sound waves. It is also possible to plot any "dead spots". If remedial measures for either condition are necessary, the effects of the corrections can be seen instantly.

DU MONT CATHODE-RAY EQUIPMENT MAY BE THE LOGICAL ANSWER TO YOUR PROBLEM!

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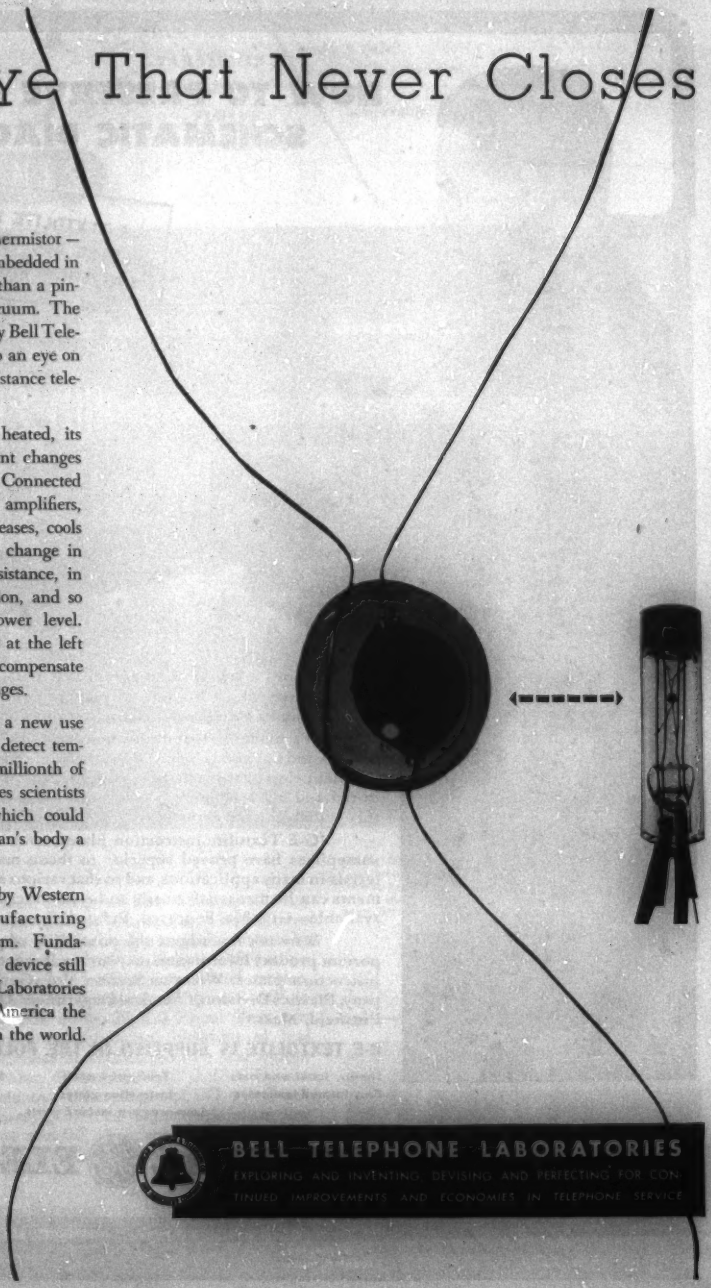
The Eye That Never Closes

You are looking at a thermistor — a speck of metallic oxide imbedded in a glass bead hardly larger than a pinhead and mounted in a vacuum. The thermistor was developed by Bell Telephone Laboratories to keep an eye on the amplification in long-distance telephone circuits.

When a thermistor is heated, its resistance to electric current changes rapidly. That is its secret. Connected in the output of repeater amplifiers, it heats up as power increases, cools as power decreases. This change in temperature alters the resistance, in turn alters the amplification, and so maintains the desired power level. Current through the wire at the left provides a little heat to compensate for local temperature changes.

Wartime need brought a new use for this device which can detect temperature changes of one-millionth of a degree. Bell Laboratories scientists produced a thermistor which could "see" the warmth of a man's body a quarter of a mile away.

Thermistors are made by Western Electric Company, manufacturing branch of the Bell System. Fundamental work on this tiny device still continues as part of the Laboratories program to keep giving America the finest telephone service in the world.



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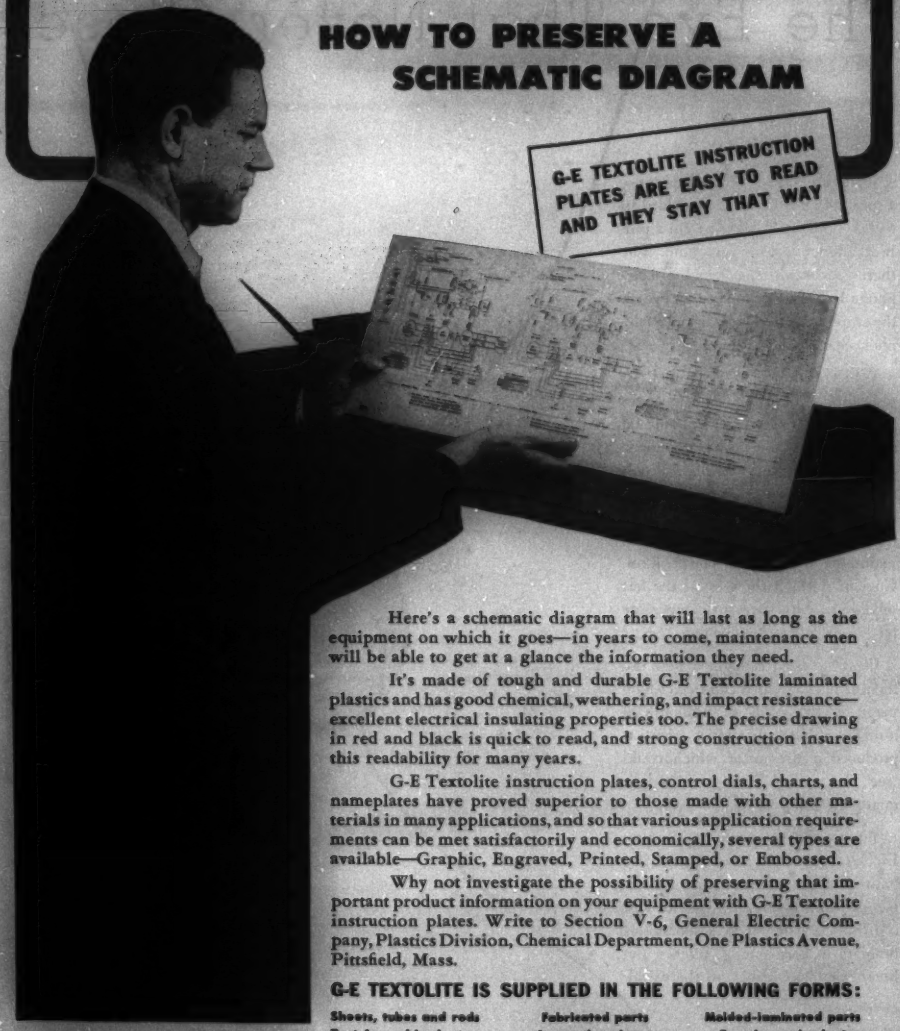
HOW TO PRESERVE A SCHEMATIC DIAGRAM



Here's a schematic diagram that will last as long as the equipment on which it goes—in years to come, maintenance men will be able to get at a glance the information they need.

It's made of tough and durable G-E Textolite laminated plastics and has good chemical, weathering, and impact resistance—excellent electrical insulating properties too. The precise drawing in red and black is quick to read, and strong construction insures this readability for many years.

G-E Textolite instruction plates, control dials, charts, and nameplates have proved superior to those made with other materials in many applications, and so that various application requirements can be met satisfactorily and economically, several types are available—Graphic, Engraved, Printed, Stamped, or Embossed.

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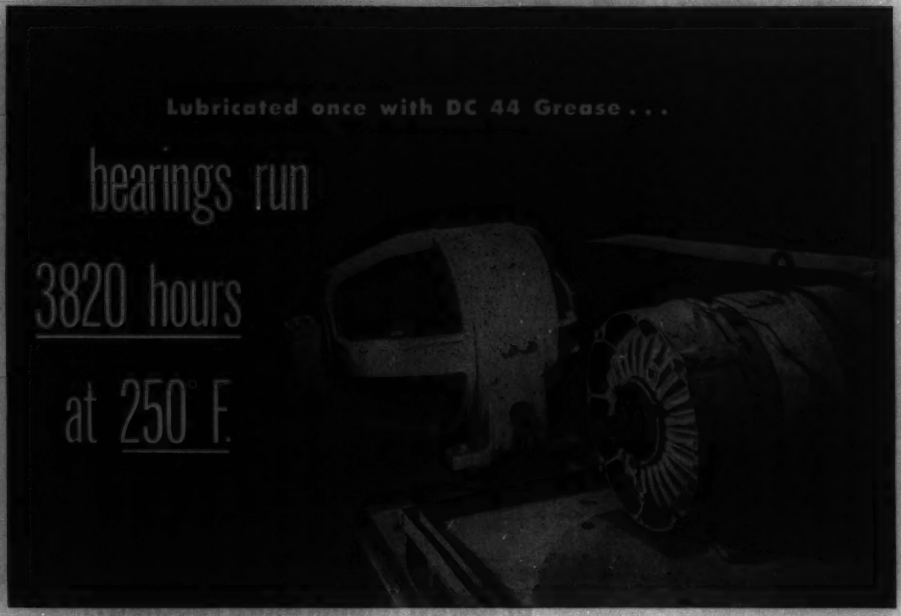
DC
DOW CORNING
SILICONES

GREASES
VARNISHES
RESINS
FLUIDS
SILASTIC*

retain their essential properties over a very wide temperature range



DC 44 Grease is tested in bearings of silicone insulated test motors overloaded to bring bearing temperatures up to 125°C. on the outer race. One application of DC 44 Grease remained serviceable for 3820 hours, 5¼ months, of operation at 125°C.

DC Silicone Greases, like other Dow Corning silicone products, permit operation at temperatures both above and below the limits of comparable organic materials. Developed originally to permit accelerated-life testing of conventionally designed silicone insulated motors, DC 44 is serviceable at temperatures from —40° to 350°F. and at speeds up to 20,000 r.p.m. Very low volatility, freedom from gumming, bleeding of less than 2% after 16 hours at 110°C. (230°F.) and weight loss of only 3.3% after 40 hours at 175°C. (347°F.) are among the conspicuous advantages of DC 44. Other DC Silicone Greases, DC 41 for high temperature low speed applications, and DC 33 for special low temperature (—70°F.) applications, are also covered in data sheet No. A7-2.

*TRADE MARK, DOW CORNING CORPORATION

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Chicago Office: Builders' Building Cleveland Office: Terminal Tower Building
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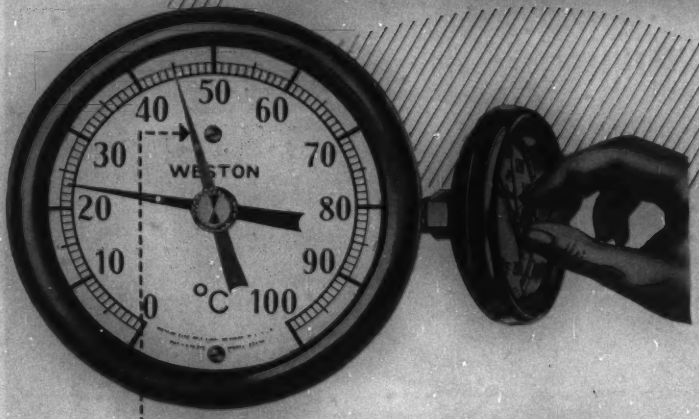

RED INDEX shows the highest or lowest temperature reached!

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The index movement in no way impairs the guaranteed high accuracy of the WESTON Thermometer.

Thus the WESTON Maximum-Minimum Thermometer provides, at only slightly above ordinary thermometer prices, a means of obtaining high or low temperature records on equipment or processes where these extreme temperatures are critical. Ideal for transformers, sterilizers, ovens, chemical equipment, food processing, etc. For complete information, consult your nearest WESTON representative. WESTON ELECTRICAL INSTRUMENT CORPORATION, 664 Frelinghuysen Avenue, Newark 5, New Jersey.

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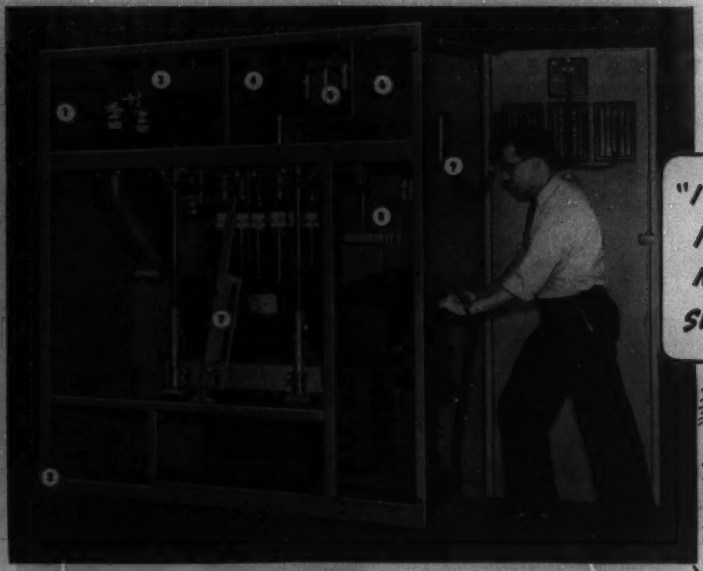

Operators Who Have This Switchgear Like It! Here are 9 Good Reasons Why:

ASK A MAN who has modern Allis-Chalmers switchgear in his plant why he likes it, and chances are that he will give not one, but several of these reasons:

1. Switchgear units are factory-built, wired and assembled. **2.** It's simple to install units, because alignment is needed at just 4 points—not 8! **3.** Changing load is easy—compartments can take current transformers of any size without rebuilding. **4.** Tightly fitted steel barriers separate compartments for buses, instrument transformers, circuit breakers, secondary wiring. For safety, units are isolated from each other!

5. Special method of insulating busbars does away with using compound filling for bus joints. **6.** Removable plates allow easy access to bus and instrument transformer compartments, circuit breakers and secondary wiring. **7.** *Fully automatic* shutters open and close orifices of primary disconnects, when breaker is removed or inserted. **8.** Elevating mechanism has *positive interlocks* which trip circuit breaker if it is in closed position when raised or lowered. **9.** "Hinged" wiring connection between door and stationary element eliminates wear or bending on wires when door is opened and closed.

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"FIRST, I want *safety,* for my operators and my equipment. Allis-Chalmers' totally-enclosed switchgear gives me all the safeguards I require . . . including automatic disconnect shutters and positive interlocks.

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"FINALLY, I want *easy maintenance* of breakers and stationary elements. A-C's switchgear scores here, too. It suits me because it offers *all three* of the advantages that mean most to a switchgear operator!"

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One of the Big 3 in Electric Power Equipment — Biggest of All in Range of Industrial Products

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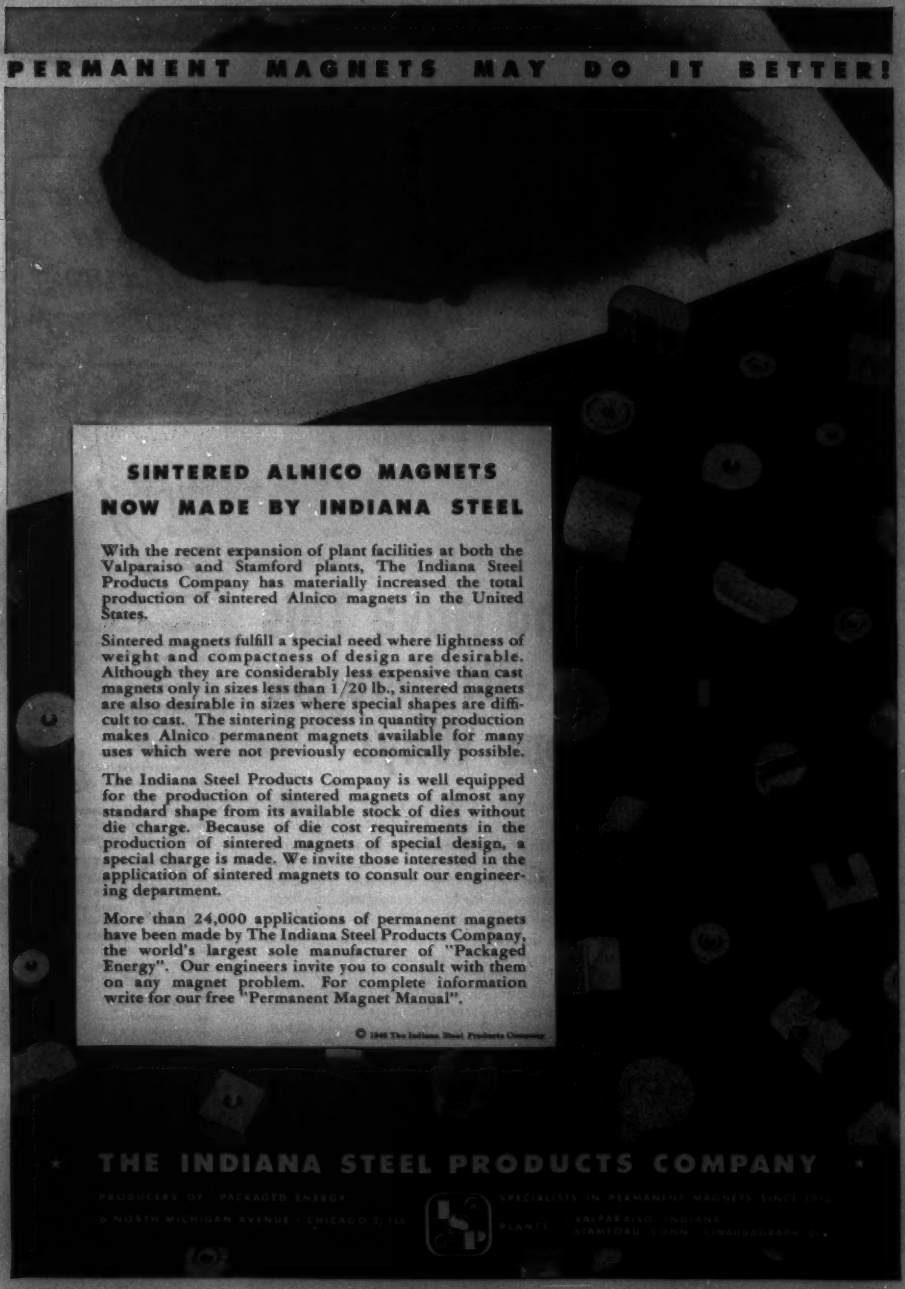
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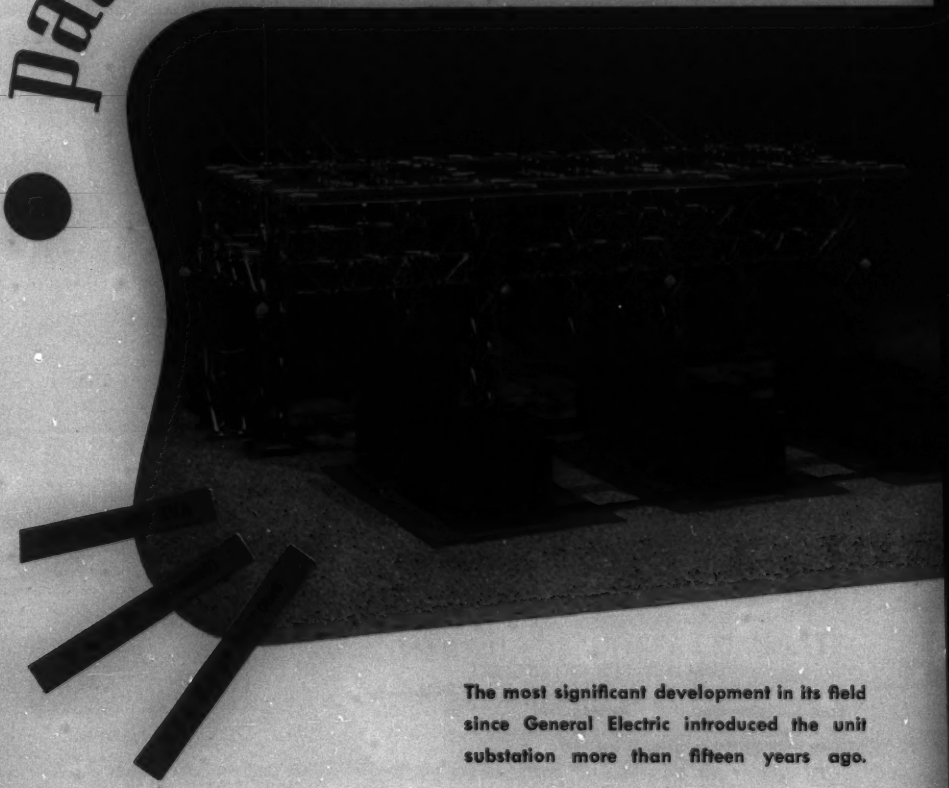

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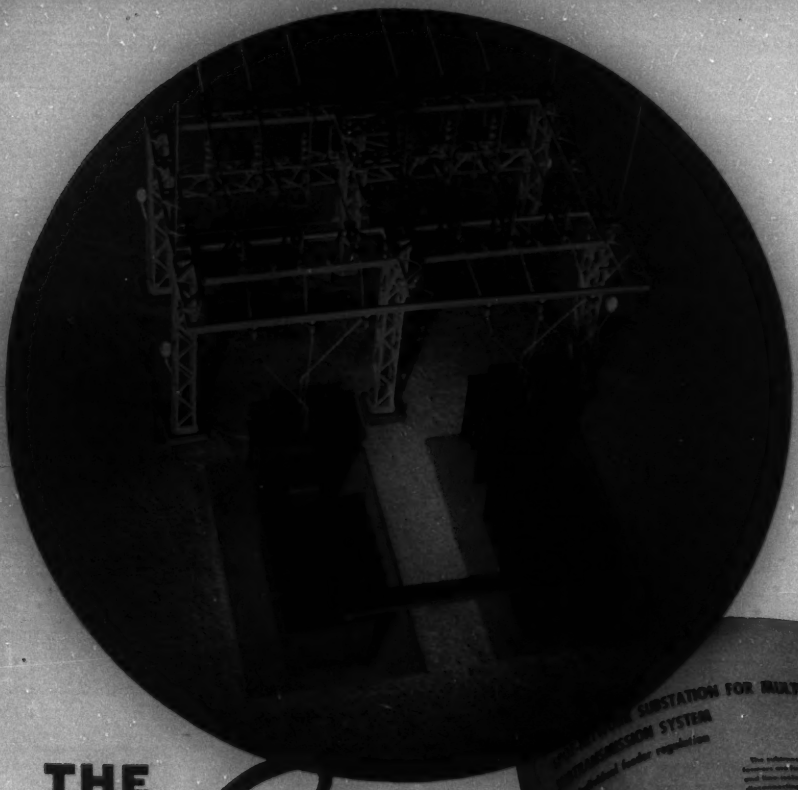

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Everything you need between the incoming high-voltage lines and the outgoing feeders is ordered, built and shipped to you as a *unit*.

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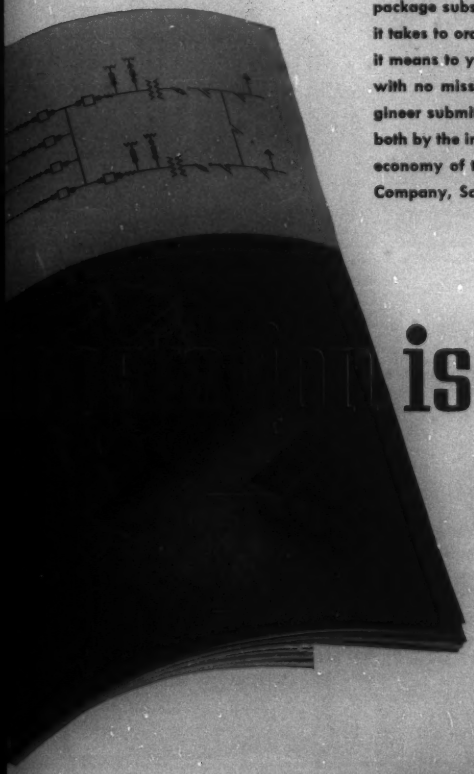
You have hundreds of package substations from which to select the one that matches your needs. This new 78-page bulletin illustrates the thirty standard types into which they fall, gives you helpful application information on each and shows you just how each will look installed. Get a copy of GEA-4500 from your G-E sales representative, or write to Apparatus Department, General Electric Co., Schenectady, N.Y.



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750 to 45,000 kva
11 to 69 kv (Incoming)
2.4 to 13.8 kv (Outgoing)

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the G-E package substation . . .
CAN GROW WITH YOUR LOAD

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The world's largest plant devoted to the design and production of molded carbon-graphite-powdered metal specialties.

Rare Metal Contacts
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CARBONS, GRAPHITES AND MOLDED METAL COMPOSITIONS

Here you see just a few of thousands of molded carbon, graphite, powdered metal and composition components manufactured by Stackpole. What you *don't* see is the tremendous background of engineering experience that goes into their production. And *that* makes a difference! It eliminates guesswork. It means that each particular product is made to conform EXACTLY to its own specific operating conditions. It means longer, more dependable service.

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When these Pressure Compensated

TERMINATION of PC Pressure Compensated Cables with gauges for checking pressure and equipment for keeping proper amount of saturant in cables.

ADVANTAGES OF PC PRESSURE COMPENSATED CABLE

1. Insulation maintained thoroughly saturated with compound at all times.
2. Internal pressure is stabilized within prescribed limits.
3. Controlled sheath stresses. There is no repeated expansion and contraction, no fatigue or splitting of lead.
4. Pressure along cable line is uniform, not variable from joint to center of section to joint.
5. Interchangeability. Cable can be spliced to existing solid type cable without difficulty.
6. Increased current carrying capacity. Many present-day limits are based on allowable sheath stress—type PC Cable controls these stresses.
7. Improvement in operating voltage stress is possible, since ionization and gas inclusions are eliminated.
8. Reduced over-all transmission cost per KVA mile.
9. Continuous sheath supervision.

Cables were loaded to CAPACITY

—temperature and pressure stayed well within prescribed limits!

THESE new PC Pressure Compensated cables are installed in a Chicago steel mill where loads are high and fluctuating.

When the big rolls crash into the steel, sudden excessive loads are created. The cumulative heating effect on the cable forces the cable saturant into three small perforated, gas-filled, lead tubes which are included in the cable assembly. The hundreds of small gas cushions thus formed absorb any excess pressure and prevent damage to the lead sheath.

When the PC Cable cools, the oil saturant contracts. The compressed gas in the tubes forces the oil back into the cable, thus preventing the wide swings from pressure to vacuum that are encountered in the ordinary cable. Additionally there is continual "sheath supervision."

Note that these operational benefits are obtained in PC Cable with no radical change in basic construction. Highly special accessories are not required. Complicated methods of installation are avoided. Maintenance costs are kept at a minimum.

SPLICES are not difficult to make. The conductors are spliced in the usual way and the gas filled tubes are spliced as shown in the illustration. The lower cable shows the completed splice.

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Tennessee Coal, Iron & Railroad Company, Birmingham, *Southern Distributors*

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UNITED STATES STEEL

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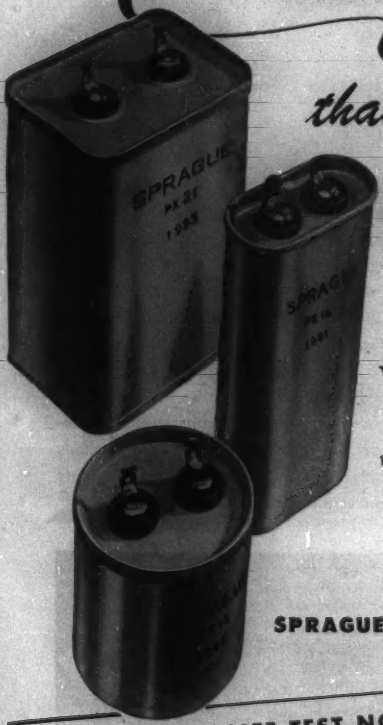
U·S·S Paper Insulated Cables

INFINITELY LONGER LIFE FOR FLUORESCENT LAMP CAPACITORS...



thanks to SPRAGUE VITAMIN Q

(REG. U. S. PAT. OFF.)

Greatly increased production facilities now permit the application of Sprague's famous Vitamin Q impregnant to ballast capacitors for fluorescent lamps—with truly outstanding results. The tables below tell the story—on severe tests that leave nothing open to question as to the remarkable superiority of these Sprague units. *NO Sprague Vitamin Q Capacitors failed during the life of the tests. ALL of the competing units did!*

SPRAGUE ELECTRIC COMPANY, North Adams, Mass.

LIFE TEST NO. 1

Tested at 490v. A.C. 85°C. in circulating air

No. Units Tested	Maker	Hours Life at Failure of each unit tested 1st	2nd	3rd	4th	5th	Impregnant
5	SPRAGUE	NO FAILURES AFTER 750 HOURS!					VITAMIN Q
5	Mfr. 1	37	124	339	498	516	Chlorinated diphenyl
2	Mfr. 2	107	243	—	—	—	Mineral Oil

POWER FACTOR

550 v. A.C. 85°C.
(as measured on a Schering bridge)

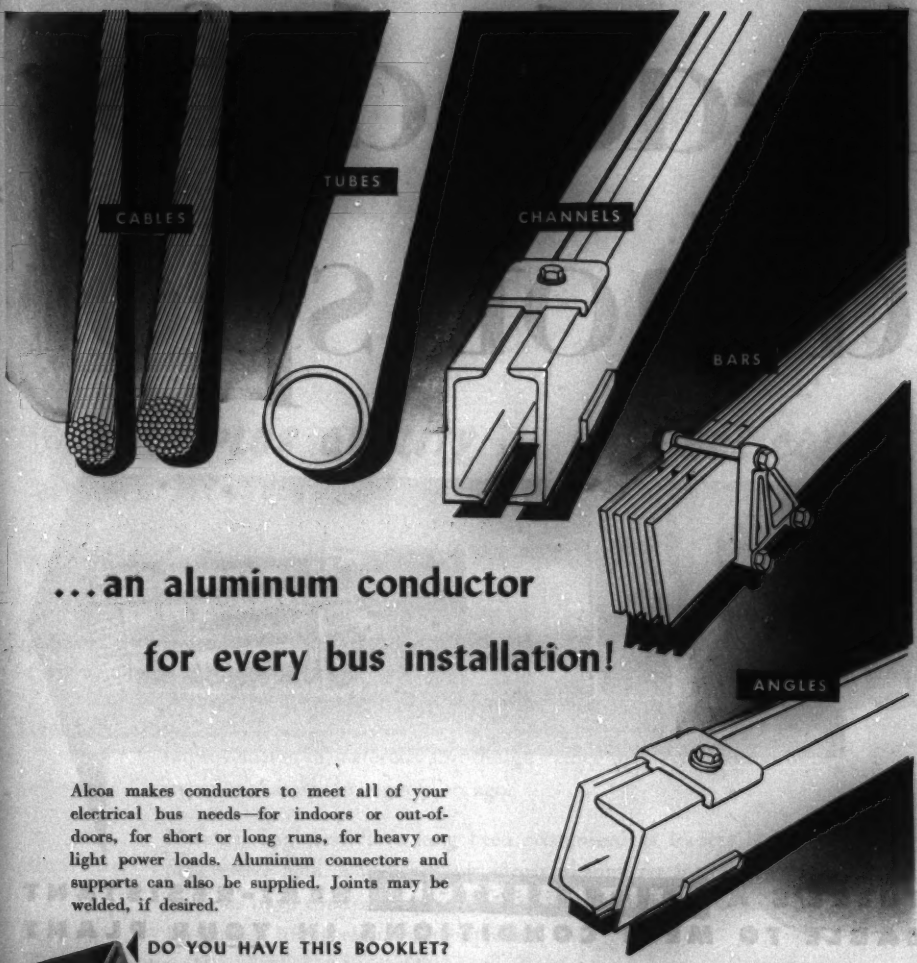
Sprague	0.27%
Mfr. 1	0.62%
Mfr. 2	0.45%

LIFE TEST NO. 2

Tested at 575v. A.C. 85°C. in still air

No. Units Tested	Maker	Results	Impregnant
4	SPRAGUE	NO FAILURES AFTER 750 HOURS!	VITAMIN Q
3	Mfr. 1	All failed in less than 4 hours	Chlorinated diphenyl
3	Mfr. 2	" " " " 4 "	Mineral Oil
3	Mfr. 3	" " " " 4 "	Mineral Oil

Units tested in both cases were standard 3½ mfd. 330v. A.C. Fluorescent Capacitors in 2" d. x 2¼" h. cans.



...an aluminum conductor for every bus installation!

Alcoa makes conductors to meet all of your electrical bus needs—for indoors or out-of-doors, for short or long runs, for heavy or light power loads. Aluminum connectors and supports can also be supplied. Joints may be welded, if desired.

DO YOU HAVE THIS BOOKLET?

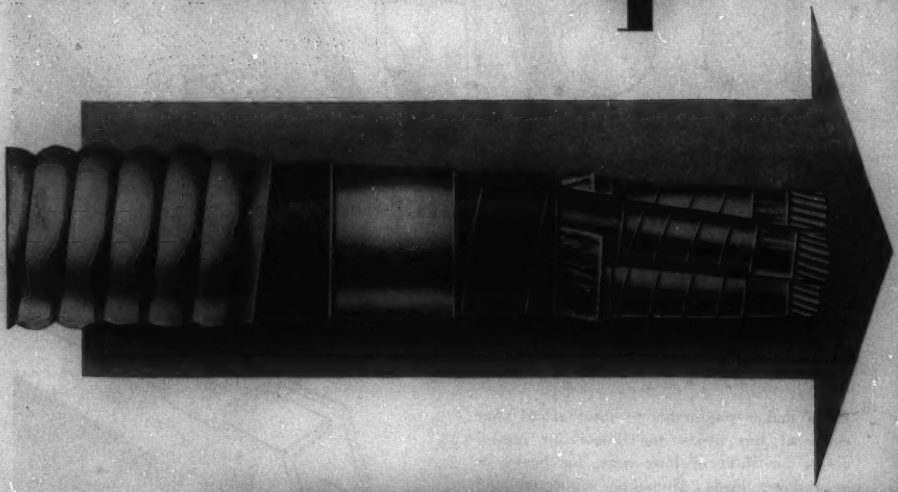
"Alcoa Aluminum Bus Conductors" contains a lot of general data which are helpful in the selection of conductors and in bus layout. We'll gladly send you a copy.

Alcoa engineers will answer your specific questions on aluminum bus conductors. For this help, call the nearby Alcoa office. Or write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA ALUMINUM

IN EVERY COMMERCIAL FORM

headed for a hot spot



THERE'S A DELTABESTON* HEAT-RESISTANT CABLE TO MEET CONDITIONS IN YOUR PLANT

Here's a multiple-conductor cable that has solved its own housing problem. Specially designed to meet unusual conditions of temperature and humidity in a large industrial plant, its highly resistant lead sheath is encased in an interlocking steel armor which serves as a conduit for the cable. It was built to be tough and, at the same time, to maintain the safety factor so necessary for plant efficiency.

Deltabeston cables have proved their worth through years of practical service on heat-resistant jobs in G-E plants and products. And this *usage-experience* can prove valuable in helping to solve your own cable problems.

If you're looking for the extra assurance of dependability and service that Deltabeston can give—or if you need a special heat-resistant cable such as the one pictured here to do a particular job, your Deltabeston distributor is ready to help you meet these specifications and to provide advice that will forestall emergencies.

For a copy of the Deltabeston Cable catalog, write Section Y17-1132, Appliance and Merchandise Department, General Electric Company, Bridgeport 2, Connecticut. Deltabeston Wires and Cables are distributed by General Electric Merchandise Distributors.

*Trade-mark Reg. U.S. Pat. Off.

GENERAL ELECTRIC

Progressive Engineering

puts PLUS QUALITY in NATIONAL COILS

The quality and life of replacement coils are the direct result of the engineering background that has gone into the design, manufacture and installation.

The progressive engineer is keen to take advantage of the latest improvements in materials and design rather than retain the construction that was in vogue years ago.

National engineers have long been recognized as leaders in the progressive field. Their constant efforts to improve materials and methods have continuously paid off in increased performance and lengthened life of electrical equipment.

If yours is an electrical rotating equipment problem, call in your nearest National engineer. Let his progressive engineering methods put "plus" into the operation of your equipment.

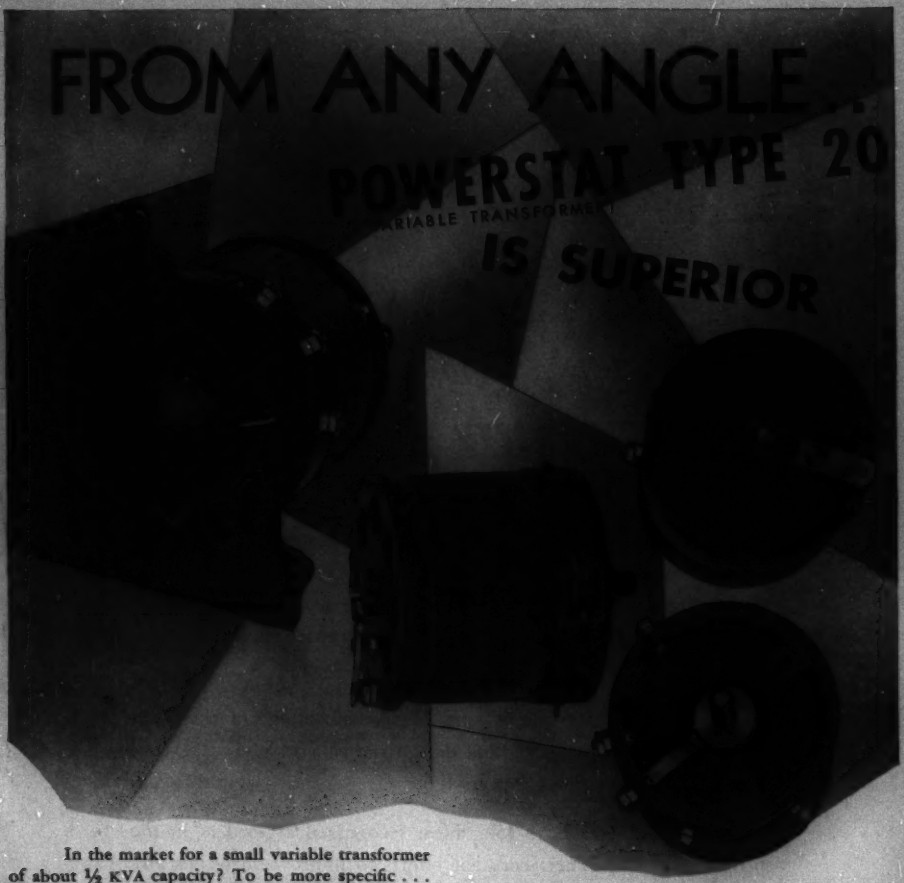
NATIONAL ELECTRIC COIL COMPANY

COLUMBUS 16, OHIO, U. S. A.

ELECTRICAL ENGINEERS: MAKERS OF ELECTRICAL COILS AND INSULATION—

TRADE MARK

REDESIGNING AND REPAIRING OF ROTATING ELECTRICAL MACHINES



In the market for a small variable transformer of about ½ KVA capacity? To be more specific . . . INPUT — 115 volts, 50/60 cycles, 1 phase. OUTPUT — 0-135 volts or 0-115 volts, 3.0 amperes.

Take a look at POWERSTAT type 20.

Viewed from any angle it qualifies as a superior voltage controller.

QUALITY ANGLE . . . The mechanical construction is extremely rugged yet this POWERSTAT is unusually compact for the rating.

Mounting holes are located on a 1¼ inch radius.

Excellent regulation, smooth control, high efficiency are only a few of its desirable electrical features.

VERSATILITY ANGLE . . . Type 20 can be connected to provide increasing voltage with either clockwise or counter-clockwise rotation. Terminals permit clip-lead or solder connections.

COST ANGLE . . . Highest valuation yet lowest price per rated ampere output of any similar type variable transformer.

Other angles regarding type 20 will be cheerfully discussed by SECO sales-engineers. . . *Consult us NOW!*

Send for Bulletin 150 EE

THE SUPERIOR ELECTRIC COMPANY

791 LAUREL STREET — BRISTOL, CONNECTICUT, U. S. A.

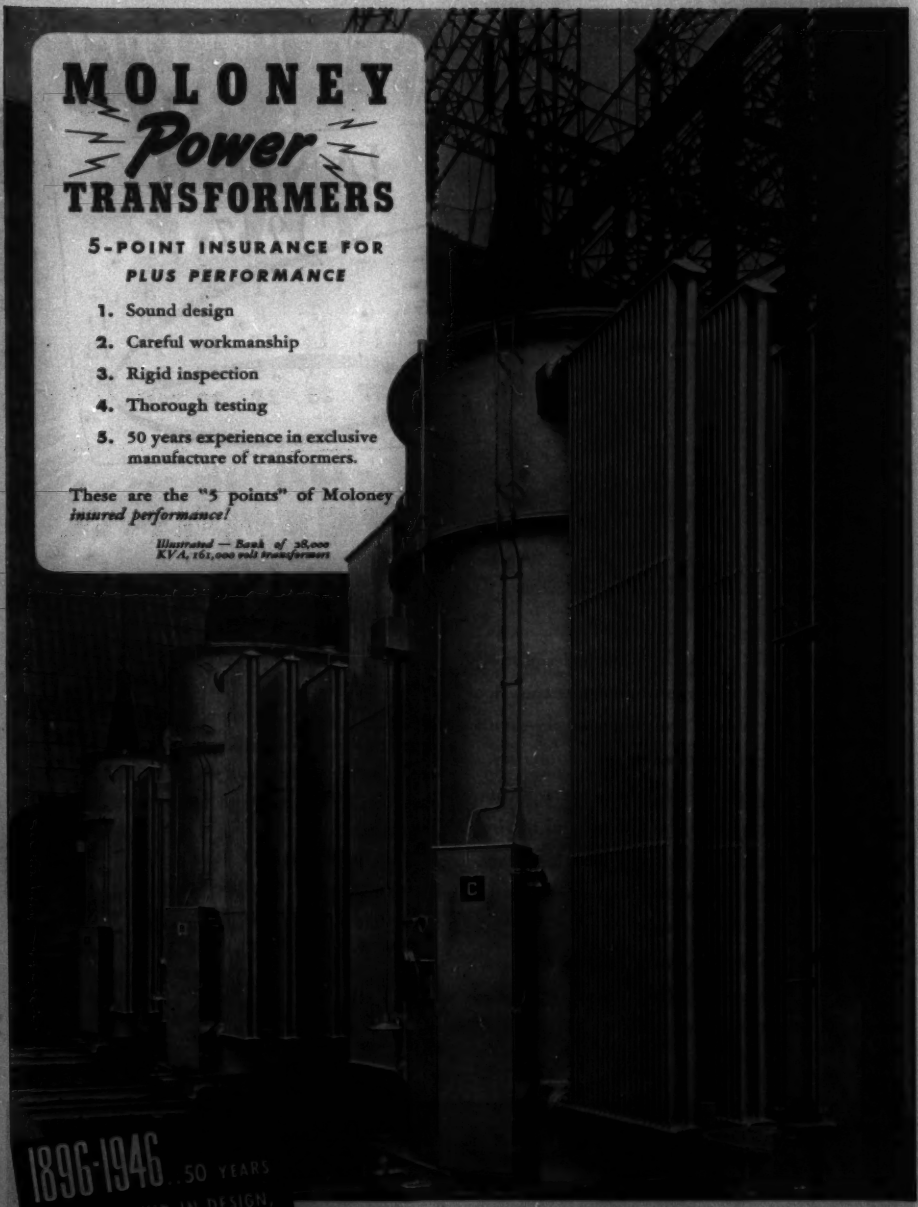
MOLONEY *Power* TRANSFORMERS

5-POINT INSURANCE FOR *PLUS PERFORMANCE*

1. Sound design
2. Careful workmanship
3. Rigid inspection
4. Thorough testing
5. 50 years experience in exclusive manufacture of transformers.

These are the "5 points" of Moloney *insured performance!*

Illustrated — Bank of 28,000 KVA, 161,000 volt transformers



1896-1946 50 YEARS OF LEADERSHIP IN DESIGN, RESEARCH, ENGINEERING

MOLONEY ELECTRIC CO. ★ ST. LOUIS 20, MO.

POWER AND DISTRIBUTION TRANSFORMERS EXCLUSIVELY SINCE 1896

Mark the date

Plan to attend

The electrical show you've wanted for years!

BY POPULAR DEMAND. Electrical engineers and operating men have wanted an exposition like this for years. They've said so—overwhelmingly—in response to questionnaires.

They've wanted to be able to see and compare—under one roof, in a minimum of time—the latest products for the generation, transmission, distribution and utilization of electric energy. And now they can!

They've wanted a comprehensive show. And—with over a hundred technically staffed exhibits—and this is it!

TIMED TO SERVE YOU MOST. The first Electrical Engineering Exposition is timed to perfection. It comes when there are probably more newly revealed developments than ever before in electrical history. It runs concurrently with the Winter Convention of A.I.E.E.—and conveniently near-by.

Plan now to attend. Post yourself on latest developments that will be helpful in your business. Improving your knowledge will make you more valuable to your company, by improving its products or services. Admission by registration only; general public excluded. Reserve the date now.

ELECTRICAL ENGINEERING EXPOSITION

71st Regiment Armory • NEW YORK • JANUARY 27-31, 1947

To be held concurrently with Winter Convention of American Institute of Electrical Engineers

Every wire in your Bethlehem strand has a smooth, highly ductile coating of zinc—applied by the bethanizing process. A cross-section, magnified, would look like two concentric circles.

There's an old saying, "Alike as two peas in a pod." But it isn't really a good comparison, for two peas are seldom identical twins. It would be much more accurate to say, "Alike as two pieces of Bethlehem Strand."

The uniformity of our strand is something we like to talk about. When you purchase Bethlehem Strand of a certain grade and construction . . . then duplicate your order next week or next month . . . you're going to find the same high quality in both lots. The same easy-handling characteristics. The same high standard of workmanship.

And the coating will be uniform, too. For Bethlehem Strand has a bethanized coating—an armor of very pure zinc applied electrolytically. No thin spots here and thick spots there. *Uniform* thickness. *Uniform* protection.

Remember, also, that the bethanized coating is available in A, B, and C weights to meet different corrosive conditions. Regardless of the weight, you'll find the coating so ductile that it will virtually eliminate flaking, peeling, and checking.

More details? We'll gladly furnish all you want.

BETHLEHEM STEEL COMPANY, BETHLEHEM, PA.

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BETHANIZED STRAND

ELECTRONICS

Designers

ACCURATE TIME AND CURRENT CONTROL

for bench welders

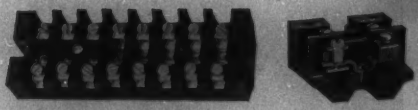
To cut welding time on small-part fabrication, such as welding solid or stranded conductors to terminals, welding electronic tube elements, or other small parts, look into the possibilities of the Thyratron-controlled bench-or-tong, low-capacity spot welder.

These alert, accurate controls, with a suitable transformer, have recorded a two-to-one advantage over soldering and rivet fabrication. Because of Thyratron welding controls' accuracy and split-cycle response, rejects drop to a new low. They are designed for either 230v or 460v, 60-cycle operation, and are rated 77 amperes peak on a duty cycle not exceeding 10 per cent. Equipment for 50-cycle operation is also available. Write for Bulletin GEA-4175A.

ONE AND A HALF INCHES

of instrument accuracy

General Electric's 1½-inch panel instruments include direct-current, radio-frequency, and audio-frequency types, in both conventional and watertight construction. All feature the compact, internal-pivot element and Textolite cases; will withstand 50 G's shock, and are accurate to within ±2 per cent. The conventional, direct-current instrument is supplied self-contained for current measurements from 100 microamperes to 10 amperes and for voltage measurements up to 150 volts. For other requirements, combinations of instruments and accessories can be had. Write for Bulletin GEA-4380.



TERMINAL BOARDS *to cut wiring time*

There's less motion and more wiring speed when terminal boards are G-E Type EB-2. Strip the wire-end, insert it in the connector, tighten a screw, and the connection is made. Each of these solderless, pressure connectors will accommodate one No. 8 stranded conductor, two No. 12 stranded conductors, or three No. 12 solid conductors, all AWG.

Type EB-1 differs from EB-2 only in its terminals, which are the conventional washer-headed screw type. Both boards are molded from strong, long-lasting Textolite, both are available in 4-, 6-, 8-, and 12-pole sizes, and are equipped with marking strips. Covers are optional. Write for Bulletin GEA-1497A.

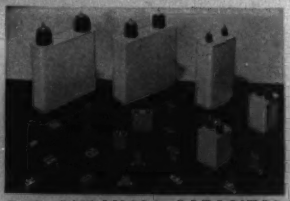
Fast Hook-ups that stay put

with **FLAMENOL WIRE**

Flamenol hook-up wire's tough, plasticized-polyvinyl-chloride insulation strips clean, bends without cracking, and is available in seven different colors. Normally, it needs no bulky armor-braid for protection. As a result, Flamenol speeds up wiring operations on electronic apparatus, where voltages do not exceed 600. Flame-resistant, corrosion-resistant, non-oxidizing, and unaffected by most hydrocarbon solvents, mild acids and alkalies, Flamenol rarely needs either attention or replacing. Its glossy finish looks new, and stays that way. Write for Bulletin GEA-4352.

Digest

TIMELY HIGHLIGHTS ON G-E COMPONENTS



NEW D-C PYRANOL* CAPACITORS

with new quality, sizes, ratings

New materials, new manufacturing techniques and strict quality control, which were so important in the excellent records d-c Pyranol capacitors made during the war, are now incorporated into a new line of d-c Pyranol capacitors built to meet exacting commercial requirements.

This new line of d-c Pyranol capacitors has a broader range of sizes, ratings, and mounting arrangements, with characteristics that allow operation through the temperature range from –55C up to 85C, at altitudes as high as 7,500 feet. Sizes range from "bathtub" up to large, welded-steel case sizes, capacitance from .01 muf to 100 muf, and voltages from 100v to 100,000v. Write *Transformer Division, General Electric Company, Pittsfield, Mass.*

*Reg. U. S. Pat. Off.

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To help train new technical personnel, and make supervisory and production men's jobs mean more, G.E. offers this 12 part talking slide film, prepared to teach even non-technical personnel the elements of electronics. It comes complete with 12 slide films and records, 300 review books, instructor's manual and carrying case; price of the kit is $100. Call your local G-E office, or order direct from *Apparatus Dept., Sect. 642-13, General Electric Co., Schenectady 5, N. Y.*

FITS AND FIT FOR

any laminated-plastic job

Because it can be fabricated with machine tools into practically unlimited numbers of shapes, G-E Textolite sheet, tube, and rod stock adds flexibility to electronic apparatus design. Over fifty different grades — each with an individual combination of electrical, mechanical, chemical, and thermal properties — assures you that tube bases, coil forms, bus-bar supports and other components will be exactly right for your job. For additional information on G-E Textolite, write to *Plastics Divisions, Chemical Department, General Electric Company, Pittsfield, Mass.*

General Electric Company, Sect. 642-13
Apparatus Department, Schenectady 5, N. Y.

Please send me

.....GEA-1497A (Terminal Boards)
.....GEA-4175A (Thyratron Welding Controls)
.....GEA-4380 (Small Panel Instruments)
.....GEA-4352 (Flamenol)

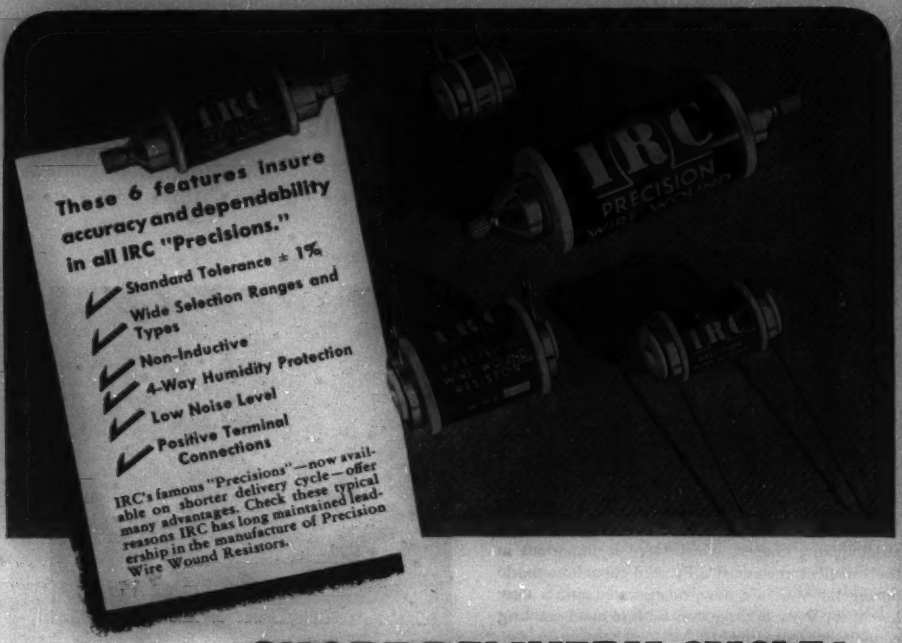
Note: More data available in Sweets File for product designers.

Name_____

Company_____

Address_____

City_____ State_____


These 6 features insure accuracy and dependability in all IRC "Precisions."
Standard Tolerance ± 1%
Wide Selection Ranges and Types
Non-Inductive
4-Way Humidity Protection
Low Noise Level
Positive Terminal Connections
IRC's famous "Precisions"—now available on shorter delivery cycle—offer many advantages. Check these typical reasons IRC has long maintained leadership in the manufacture of Precision Wire Wound Resistors.
IRC
PRECISION

SHORT DELIVERY CYCLE!

IRC PRECISION WIRE WOUND RESISTORS

1. Accuracy. IRC offers standard tolerance of ± 1% . . . tolerances as low as .5, .25 and .10% available on special order.

2. Wide Selection Ranges and Types. Select whatever range, size or type you need to suit your design. IRC Precision Wire Wound Resistors are available in ranges from 0.1 ohm to 2.5 megohms. IRC also offers a wide selection of sizes and terminal types.

3. Non-Inductive. The largest possible special alloy enamelled wire, wound on winding forms without a break in insulation, with adjacent sections in opposite directions, allows windings of low residual inductance. The frequency characteristics of IRC Precision Wire Wound Resistors suit them for use at audio and carrier frequencies up to 50 KC.

4. Low Noise Level. Specify IRC Precision Wire Wound Resistors for instruments that require lowest possible noise level.

5. Protection Against Atmospheric Conditions. Non-hygroscopic ceramic winding forms are specially impregnated for additional moisture protection and to prevent abrasion of enamelled-wire windings. Windings are impregnated with special varnish, which improves insulation, eliminates breakdowns and shorted turns. This impregnating compound hardens with high temperatures instead of softening as is the case with wax impregnation found in some wire wound resistors. Baked impregnation of windings secures wires rigidly in place and gives effective protection from high humidity. For further protection, extra insulation coatings are applied before and after labeling.

6. Terminals. To insure positive terminal connections, IRC molded contacts are used on Precision Wire Wound Resistors.

Your IRC Sales Engineer can quote you definite delivery schedules, or address inquiries to Dept. 5K.

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IRC
FIXED & VARIABLE RESISTORS

INTERNATIONAL RESISTANCE CO.

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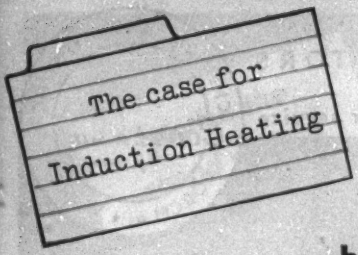


breathing new life into diaphragm assemblies

...4 every 10 seconds

If your business involves complicated assemblies, the way induction heating breathed new life into this diaphragm assembly will hold high interest for you.

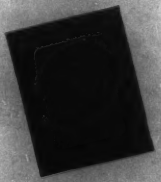
It's unique in soldering jobs because it brought special problems in soldering around the center of one piece and the rim of the second. The first part soldered around the center must be held so solder won't drip off the edges. Yet the second piece must be positioned so the heat will penetrate to its center, while only reaching the rim of the other.

Experiments led to the final pattern of heating both pieces in a 4-turn, series-connected, inductor coil, the complete fixture consisting of two such units. Equipped with two standard Westinghouse 5-kw r.f. generators, the system works so well it will solder four complete assemblies in 10 seconds!

You gain in all types of modern radio frequency heating, both induction and dielectric, in any phase of heat-treating . . . annealing, brazing, hardening, sintering, curing, bonding, drying and molding.

Write, wire or phone your nearest Westinghouse office today for all the facts. Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pennsylvania.

J-06163



HERE'S FREE HELPFUL INFORMATION

on both induction and dielectric heating . . . their principles and theories; where to use them; how to select them; actual case histories of their use. Write for your copy today, on your business letterhead, please. Ask for B-3620.

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INSULATORS
never fail
in rectifier service

CHEMICAL AND SCIENTIFIC
Coors is best by every test.
PORCELAIN WARE

Coors insulators being assembled in rectifier units.

Battery of twenty-four 12-tank Allis-Chalmers Excitron Assemblies supplying power to two Aluminum reduction circuits; high-speed anode breakers on left, cathode breakers on right.

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GOLDEN, COLORADO

AMPERITE

DELAY RELAYS
PROVIDE DELAYS RANGING FROM 1 TO 120 SECONDS

Other important features include:

1. Compensated for ambient temperature changes from —40° to 110°F.
2. Contact ratings up to 115V-10a AC.
3. Hermetically sealed — not affected by altitude, moisture or other climate changes . . . Explosion-proof.
4. Octal radio base permits easy replacement.
5. Compact, light, rugged, inexpensive.
6. Circuits available: SPST Normally Open; SPST Normally Closed.

WHAT'S YOUR PROBLEM? Send for "Special Problem ... and Descriptive ...

with porcelain heater

with heater wound directly on blade

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561 BROADWAY
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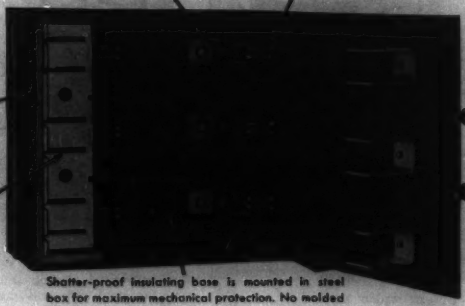
Exclusive Manufacturers of Transformers to the ELECTRONIC INDUSTRY

Notice the sound design and rugged construction of this Saflex Switch Unit

A good reason for choosing Saflex Distribution Panelboards



Solder-solderless lugs can be used either as solderless connectors or as solder lugs or both. Furnished on all except 30 ampere, 250 volt units.

Positive pressure fuse clips have high conductivity and assure automatic contact pressure at the fuse terminals without auxiliary parts.

Cam-action provided by handles near switch jaws where it is most needed. This cam-action supplies (with minimum manual effort) the considerable force necessary to provide high contact pressure.

Cover can be locked in either the ON or OFF position by means of a padlock on the bracket.

Arc suppressor block greatly increases the rupturing capacity.

Ranging from 30 to 600 amperes, Saflex Switch units are for use in systems up to 575 volts A.C. or 250 volts D.C.

Shatter-proof insulating base is mounted in steel box for maximum mechanical protection. No molded parts are exposed when cover is closed.

● Notice how simplicity, sturdiness, and safety are built into Saflex Switch units. Opening and closing unit doors operates switch units. Door is permanently anchored; it carries switch blade assembly only, and covers all live parts when closed. When door is open, all accessible live current-carrying parts are dead. All circuits may be opened safely under maximum load. All poles are broken simultaneously, preventing single-phasing. All units except 600 ampere size have rotary switch units. Yale locks on panel cabinet doors prevent unauthorized access. • For fast, simple installation, panel box has oversize wiring gutters and may be shipped separately for roughing in during early stages of construction. Interior and front are separate units, and may be installed later.

Write for Bulletin 2500. Address Square D Company, 6060 Rivard Street, Detroit 11, Michigan.

SQUARE D COMPANY

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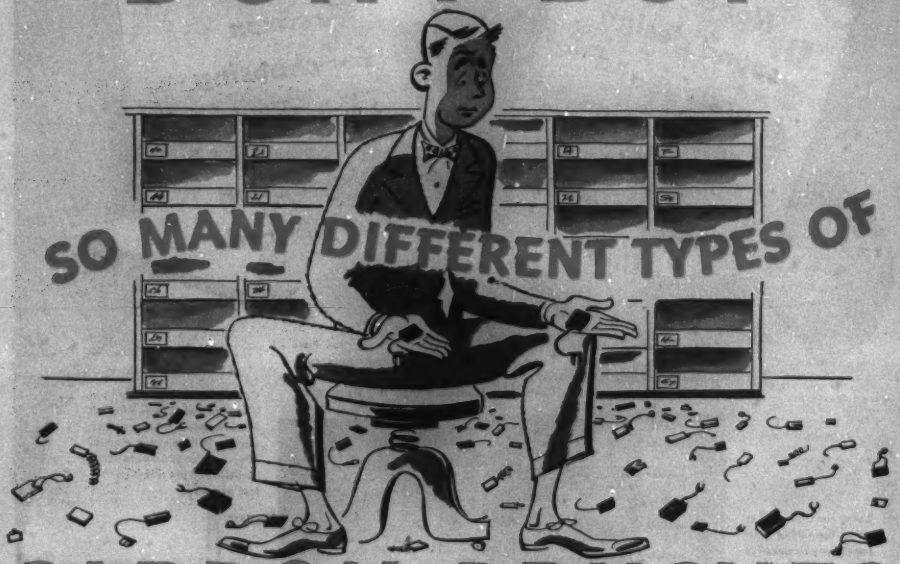

CARBON BRUSHES

IT'S A FACT—you don't *need* to buy so many different types and sizes of motor and generator brushes! This has been established by surveys in various plants! A large steel company, for instance, discovered it could cut its brush items from 675 to 93. Another firm eliminated 2285 "necessary" brush sizes and shapes at substantial savings in ordering, billing, and in inventories.

Sponsored by National Carbon Company, Inc., this program of simplification of carbon, graphite, and metal-graphite brush needs can bring similar savings to you.

By making a few simple changes in present brush specifications, a comparatively few standard brush types and sizes will fill most of your varied needs.

HOW BRUSH SIMPLIFICATION PAYS:

1. Price advantage through quantity discounts.
2. Less money and space tied up in brush stocks.
3. Less time needed to handle stock.
4. Reduction of small orders—saving time in bookkeeping, billing, and accounting.

For further facts, get in touch with our nearest Division Office today. Dept. EE.

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Division Sales Offices: Atlanta, Chicago, Dallas, Kansas City, New York, Pittsburgh, San Francisco

ONE UNYIELDING STANDARD OF QUALITY . . .

3" ROUND CASE
Shroud Style
Flange diameter, 3½"; body diameter, 2¾"; scale length, 2-9/16". Bakelite case.

2" ROUND CASE
Shroud Style
Flange diameter, 2¾"; depth overall, 2-5/16"; body diameter, 2-11/64"; scale length, 1⅞". Bakelite case.

3" ROUND CASE
Open Face Style
Flange diameter, 3½"; body diameter, 2¾"; scale length, 2-9/16". Bakelite case.

2" ROUND CASE
Open Face Style
Flange diameter, 2¾"; depth overall, 2-5/16"; body diameter, 2-11/64"; scale length, 1⅞". Bakelite case.

3" RECTANGULAR CASE
Width, 3"; height, 3⅛". Mounts in round hole. Body diameter, 2¾". Bakelite case.

2" RECTANGULAR CASE
2½" square. Mounts in round hole. Body diameter, 2-3/16". Bakelite case.

SIMPSON instruments do not have merely an international reputation—they have an international reputation for *quality*. Let any man familiar with electrical test instruments hear the name Simpson and he thinks immediately "accuracy — lasting accuracy — beautiful design — quality construction that endures". Because no Simpson instrument has ever been marketed unless its makers had first assured themselves that it was better than any similar existing instrument, Simpson customers have always the protection of quality. They know that, no matter what problems of materials and manufacture arise, the Simpson instrument they buy is of top quality or they would never have been able to buy it.

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MODEL 260
High Sensitivity Set Tester

Simpson
INSTRUMENTS THAT STAY ACCURATE

MOTOR STARTING *Capacitors*

● Aerovox pioneered the high-capacity electrolytic motor-starting capacitor. The major portion of such capacitors in daily use were made by Aerovox, and Aerovox has kept faith with manufacturers and owners of capacitor-start motor equipment by providing the outstanding line of replacements.

Such capacitors are available in both electrolytic and oil-filled types. Widest selection of capacitance and voltage ratings, containers, mountings, terminals.

● DATA *on request* . . .

Latest catalog lists both exact-duplicate and universal types. Also practical data on the selection and operation of such equipment. Write for your copy. Also, submit that capacitor problem or requirement.

AEROVOX capacitors

FOR RADIO-ELECTRONIC AND INDUSTRIAL APPLICATIONS

PHASE SEQUENCE INDICATOR

—with NO Moving Parts

Just connect the three permanent leads, in any order, to the circuit under test and the phase sequence is quickly and simply determined. No combination of leads from various binding posts to arrange—no loose leads to become lost.

This instrument will prove most useful to industrial engineers, meter men, trouble shooters, electricians and maintenance personnel.

MEASUREMENTS CORPORATION

BOONTON NEW JERSEY

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SETS • AMPLIFIERS

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Revised! Up-to-the minute! Listing the newest, the latest and best in RADIO PARTS, RADIO SETS, AMPLIFIERS, AMATEUR GEAR, ELECTRONIC EQUIPMENT, SUPPLIES and ACCESSORIES! Hundreds of items for every Radio and Electronic need—Condensers, Resistors, Transformers, Tubes, Test Equipment, Tools and Repair, Replacement and Maintenance Parts of every kind. ••• All standard top quality, nationally famous makes, are fully represented in the great new Concord Catalog. Complete lines including new and hard-to-get parts and equipment at latest O.P.A. prices or lower. Thousands of items—and complete stocks ready for immediate shipment from CHICAGO or ATLANTA. Your copy of the new Concord Catalog is ready now—FREE! Mail the Coupon below.

10H 40 MA. CHOKE

Extremely compact highly efficient choke with satin finish for auto radio receivers and AC/DC radios. Also excellent filter choke for other receivers and amplifiers. 1 5/8" x 1¼" x 1¼" ins. Unshielded strap type mounting. C160F ..... 46¢

Midget Electrolytic

Midget dry electrolytic will handle any job requiring an electrolytic capacitor. Polarity clearly indicated. Have 10" wire leads. Easily replaces larger capacitors. Cap. Mfd 20-20. DC-Working Volts 150. C2125 ..... 60¢

ROTARY SWITCH

Single gang, 6 pole, 2 position, shorting switch. 1 1/16" dia. with ¼" shaft dia. Threaded bushing ⅜" long. ¼" shaft. Bushed. 39¢

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SEE . . . the first peacetime Concord line of modern Radio Sets and Radio Phonograph combinations—featuring a host of new, approved post-war developments . . . richer tone quality . . . super-selective tuning and reception . . . high fidelity . . . new modern design cabinets.

SEE . . . the thrilling new MULTIAMP Add-A-Unit Amplifiers, entirely new and revolutionary development in amplifier engineering. Sensational flexibility, power, fidelity and economy, exclusive with Concord!

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No. 45, AIEE Standards

December, 1945 Edition

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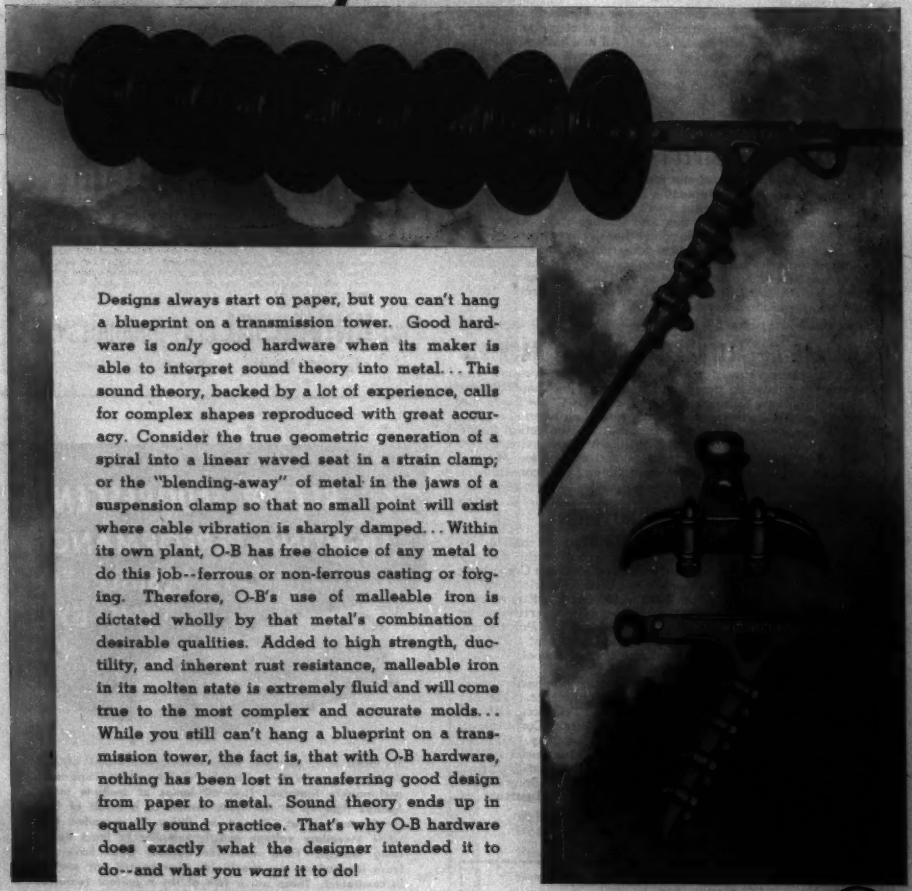

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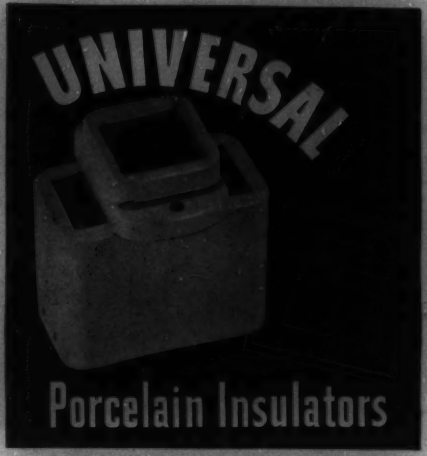

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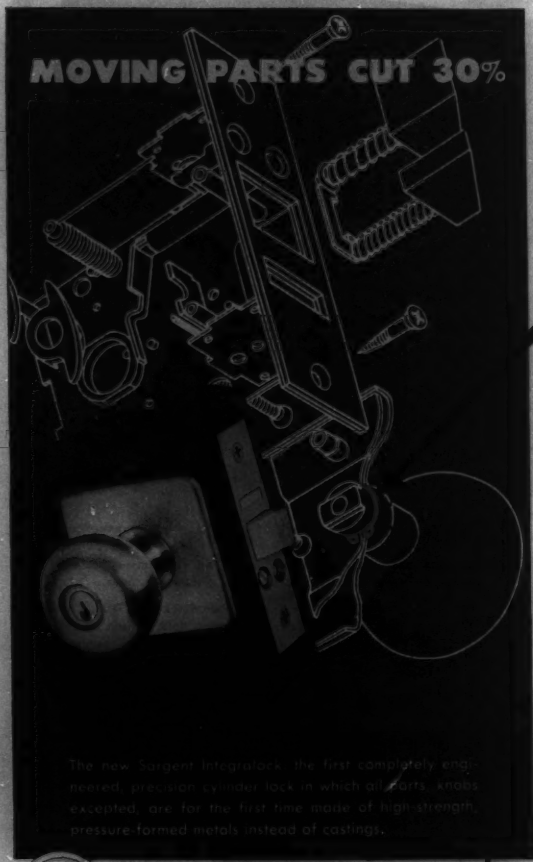

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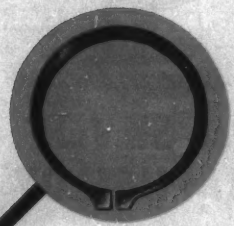

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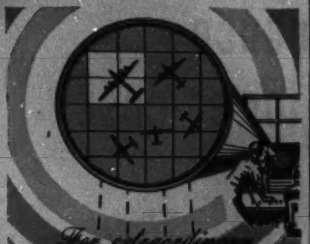

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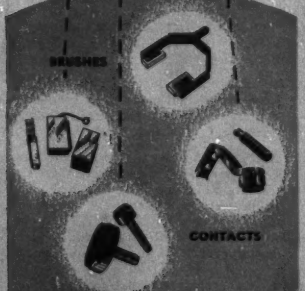

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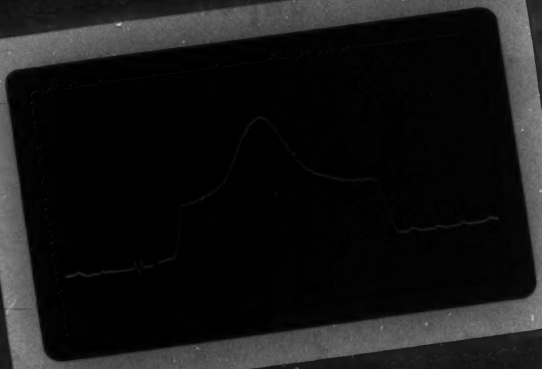

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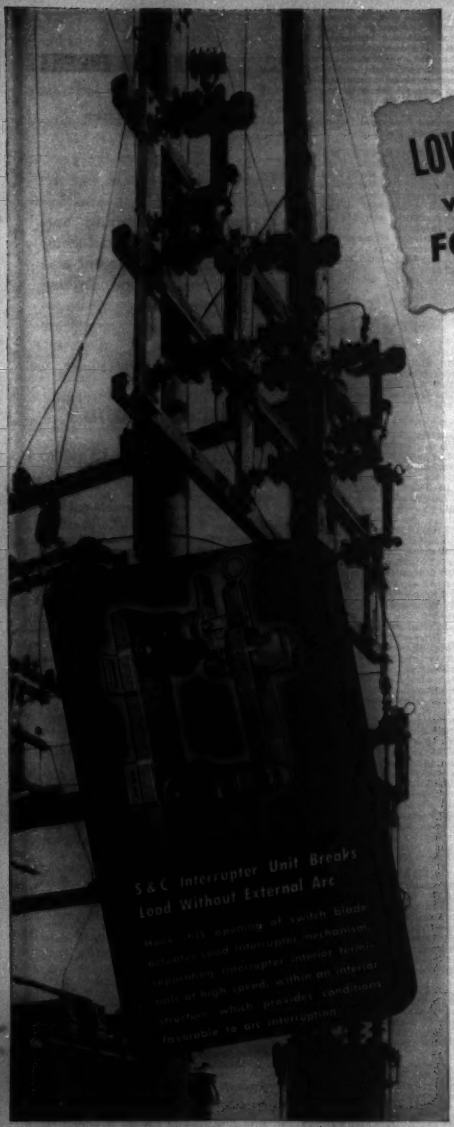

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PROFESSORS of electrical engineering, Ph.D. or D.Sc. degree, 35–45, with considerable experience instructing radio engineering, including broad experience in use of radio equipment and apparatus; some experience with commercial organization as design or development engineer on radio equipment and with background and training in electromagnetic theory. Location, upstate New York. W-7678.

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INSTRUCTOR, electrical graduate, to teach direct and alternating current theory and machinery laboratory, and probably electricity and magnetism. Salary, $3000 a year. Opportunity to teach evenings. Location, Pennsylvania. W-7814.

SALES ENGINEERS, 28–32, mechanical, electrical or aeronautical graduate, with five to six years' application experience in aircraft industry. Salary, $3600–$4800 a year. Location, northern New Jersey. W-7832 (a).

ASSISTANT to Division Engineer, 35–45, mechanical or electrical graduate or equivalent with ten years' power plant experience, to develop basic data for power plant design and utilities distribution; check and recommend improvements in operating and maintenance procedures; prepare equipment specifications and make heat balances. Some traveling. Salary, $5200 a year. Location, Pennsylvania. W-7841.

ASSISTANT PROFESSOR of electrical engineering, Master's degree, preferably with some electronic experience. Location, Rhode Island. W-7872.

TECHNICAL WRITER, 26–35, electrical graduate or equivalent, with three to five years' experience, preferably in instruction, maintenance and sales manuals, etc., to prepare, for final approval, finished copy and layouts covering technical information relating to mechanical, electrical, electronic and hydraulic devices and equipment. Salary, approximately $4490 a year. Location, northern New Jersey. W-7877.

RESEARCH ASSOCIATES OR ASSISTANTS, 25–35, preferably with M.S., for fields of ceramic, chemical, mechanical, electrical or metallurgy. Salaries, $3000–$4200 a year. Location, North Carolina. W-7907.

INSTRUMENT ENGINEER, electrical. Should be familiar with design, development and production of industrial instruments, preferably with ability to supervise other employees. Salary to start, $4000–$5000 a year. Location, northern New Jersey. W-7915.

ELECTRICAL ENGINEER, 25–30, magnetic measurement laboratory work. Salary, $5000 a year. Location, northern New Jersey. W-7924.

ELECTRICAL ENGINEER, graduate, with at least five years' experience in layout and design of rectifier substations, to make power studies, prepare specifications and do general layout work. Salary, $5000–$6000 a year. Location, New York, N.Y. W-7954.

ELECTRICAL BUYER, young, experienced in the purchasing and expediting of all types of electrical equipment from connection wires to automatic electric control, taking in the purchase of transformers and motors. Location, Pennsylvania. W-7957(a).

ELECTRONICS ENGINEERS for application of electronic techniques to chemical process measurements and control problems. Will be engaged in the development of special measuring instruments and process controls for the improvement of quality and yield and for the reduction of the cost of operating labor. B.S. or preferably M.S. in physics or engineering. General knowledge of chemistry (2 years college chemistry), two years' experience in the development of electronic measuring instruments, experience on the design of radar circuits or in servo mechanism techniques can be included under the above requirement. Location, Delaware. W-7964.

ELECTRICAL ENGINEER with B.S. degree and at least five years' experience in electronic design field, including radar for circuit development of radar equipment for ground and marine use, fire control and other fields. Salary, $4800–$6500 a year. Location, northern New Jersey. W-7969.

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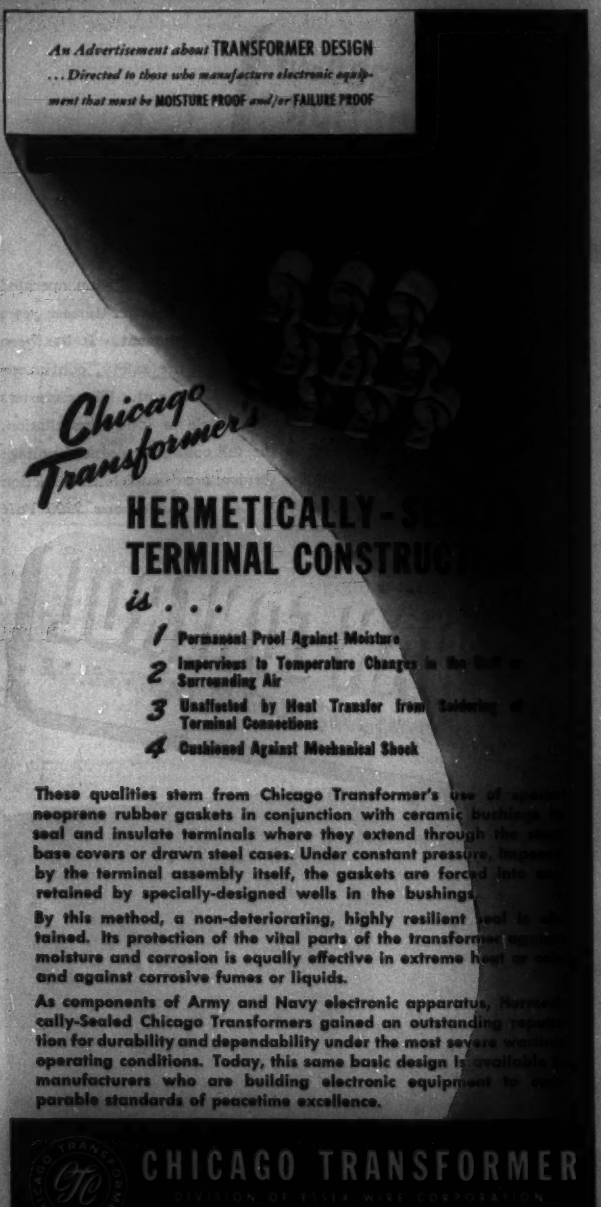
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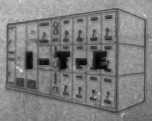

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